Extended Abstract

Title: "Increasing Energy Efficiency in the Web Coating Process"

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Introduction

The Web Coating & Laminating process is very dependent on fossil fuels, petroleum, coal and gas as a source of energy for the numerous process functions, etc. Historically, in the United States, there has been virtually unlimited availability of fossil fuels at reasonable price. As a result, energy costs were minimal and there was little concern about adequate supply.

However, in recent years, the costs for fossil fuels have significantly escalated as shown in Fig. 1 below, and current prices for crude oil are in the range of $105-120 /barrel (with a July 11, 2008 peak of $147.27).

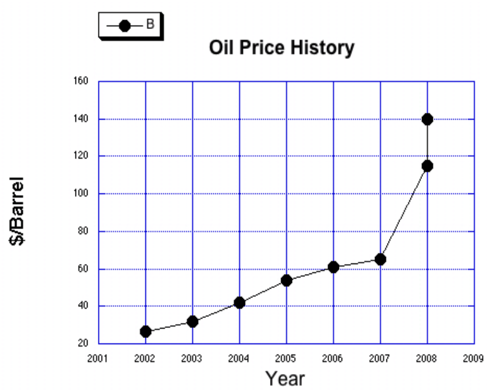


Fig. 1 – Crude Oil Price Curve

In addition, rapid growth in China, India and Southeast Asia has increased global demand, yet the rate of development of new oil supplies is not keeping up with the rate of consumption. In other words, fossil fuel based energy costs are likely to continue to escalate and future production may not be able to satisfy demand.

In order to remain competitive in this climate of rising energy costs, all personnel in the converting industry must start focusing on reducing energy consumption, modifying processes to be more efficient, and utilizing renewable resources in their production facilities. Our goal in authoring this paper is to encourage converting industry professionals to consider minimizing the energy requirements of their products and processes and realize the significant benefits associated with the implementation of a Total Energy Management (TEM) system. Potential areas for energy savings will also be discussed.

Why Focus On Energy Efficiency?

According to a study done by the National Association of Manufacturers[1], energy costs for a typical manufacturing operation usually range between 2-5% of total production costs. As a result of this relatively low cost contribution, energy usage can often be overlooked when cost control programs are conceived and introduced. This is a serious mistake, for a number of reasons noted in the referenced report.

1. Industry surveys have indicated that the average manufacturer can save between 10 – 20 % of total production energy consumed and that as much as 30% of these saving can come without any capital expenditures.
2. Resource conservation efforts often yield very high returns on investment. For instance, according to the report, Frito Lay's efforts routinely earn 30% ROI and DuPont has claimed over 75 Six Sigma™ projects (implemented without capital expenditure) that have produced over $250,000 per project in cost savings.
3. Many energy efficiency projects result in product quality improvement, waste reduction, improved product throughput and increased uptime that often have a much larger positive impact on cost per unit production than the energy savings alone.
4. Saving energy or improving efficiency usually provides some intangible, but increasingly more marketable, value-added benefits like; a "greener image", a "smaller carbon footprint" a more "sustainable" process and product, and a corporate culture promoting "lean manufacturing" and "continuous improvement."
5. There are many new business development opportunities related to "energy efficient", "green" or

"environmentally responsible" end products and processes.

6. There are potential reductions in USEPA compliance costs associated with corresponding reductions in fuel usage.
7. Federal and state programs are available to help companies identify, assess and implement energy savings plans, including some that will provide financial incentives to improve ROI.

<u>OK, So Where Do We Start?</u>

The first step in any company's attempt to implement a process energy management program is to conduct a process energy audit. Most times this be handled "in-house" by the plant engineering and maintenance staff. However, if insufficient time, personnel availability, or inappropriate in-house skill sets do not allow this approach, a company can always seek outside help. Such assistance is readily available in the form of qualified vendors, consultants and/or state government expertise offered under the umbrella of the Department of Energy "Industrial Technology Program."[2]

Once the major energy consumers in the coating and laminating process have been identified, we can begin to examine methods available to reduce process energy consumption without sacrificing product quality, process safety or environmental stewardship.

<u>Categories of Coating Line Energy Use:</u>

Energy Inputs

Electrical:	Motors, drives, coating supply pumps, air handling equipment, controls, lighting, material handling equipment, mixing equipment, dryer retraction, process dampers, building MUA conditioning equipment, machine process sensors (BETA gauges, humidity monitors, LEL monitors etc), Electric Convection, EB, UV, or IR curing and drying equipment
Thermal:	Fossil fuel-fired heat sources, Heat of friction (fans, rolls etc), exothermic chemical reactions in coatings, solvent exothermic reactions, and radiant energy losses to atmosphere

Mapping total process energy use involves identifying the process loads, determining the energy input sources, calculating system efficiency losses and arriving at an energy balance. For purposes of evaluating and comparing component energy usage, this paper will quantify energy in units of Kw.

The line drawing below (Fig. 2) is intended to represent a "typical" coating and laminating process and will be used as a reference for the purposes of this paper. The line features a single station, coating line with a drying/curing module and an inline laminating station, with turret unwinds and rewinds. Naturally, other line configurations and equipment types could be used for any particular coating and laminating process.

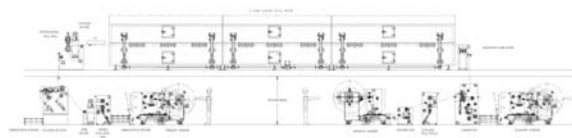


Fig. 2. "Typical" Coater Laminator Line Arrangement

In order to create a workable energy balance model for comparison of energy usage between commonly used coating, drying, and curing technology, the authors have arbitrarily assigned the following process operating case:

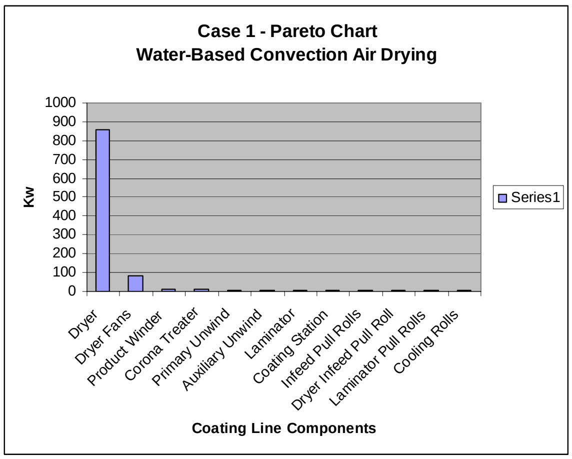
Line Speed:	1000 FPM
Substrate:	0.004" PET
Web Width:	60"
Dry Coat Weight:	10 GSM
Solids Content:	50% for water-based 25% for solvent case 100% for hot melt

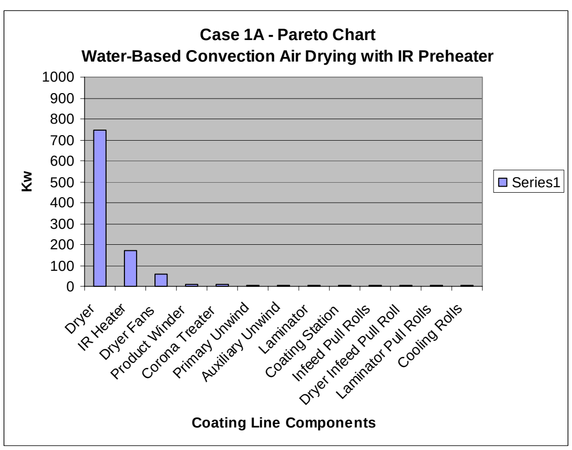
Once component energy consumption has been measured or estimated, the next step in the process of evaluating process energy usage and defining a strategy for reducing consumption is to determine where best to focus our labor hours and/or capital dollars. The Pareto chart is a useful tool for identifying the "low hanging fruit," (i.e. the equipment or processes that use the most energy and thereby may offer the best opportunity for savings). The charts below (Fig. 3) compare the energy use of each of the coating line process components in each specified case, using Kw as a common unit of energy.

Case 1 - Assumes the use of a three-zone, convection air dryer.

Case 1A - Assumes the use of a shorter length, three-zone, convection air dryer with IR preheater.

Case 2 - Assumes the use of a three-zone, convection air dryer.





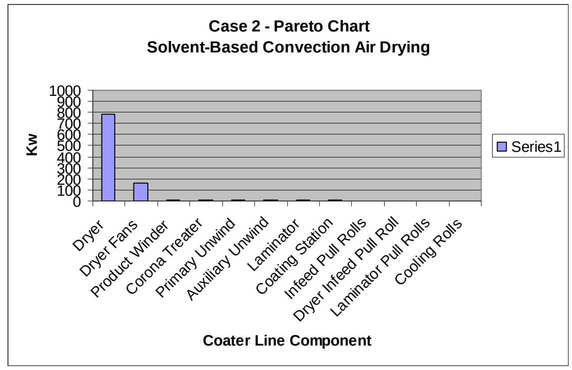


Fig 3. – Pareto Chart Evaluation of Coating Line Energy Users

For all cases, it is quite clear that the drying component and related fans consume the largest amount of energy by far. As such, the dryer represents the best opportunity for energy savings or efficiency improvements.

Now that we have a good idea of where to focus first, we can use 'value stream mapping' to further refine the scope of our efforts. In value stream mapping, each discrete process is broken down into a set of finite elements that either contribute, or not, to the overall value of the process/product. As an example, for water or solvent-based coated products, the dyer/drying process can be broken into several process elements; there is a web conveyance function, a solvent evaporation function, a web heating function, a safe operating function, an air heating function, and a radiation heating function. Of these discrete functions, only the web conveyance, evaporation and safety functions truly add value to the process (i.e. we need to transport the web, dry or cure the adhesive and maintain a safe operating condition throughout). Heating both the web and supply air is necessary in order to promote evaporation and can be considered "value-neutral", but heating the air that is exhausted from the dryer to atmosphere, and heating the air surrounding the dryer are clearly unintended, non-value added functions (Fig 4). Therefore, we want to focus our initial energy reduction or efficiency improvement efforts on eliminating or limiting the negative impact of these unintended functions.

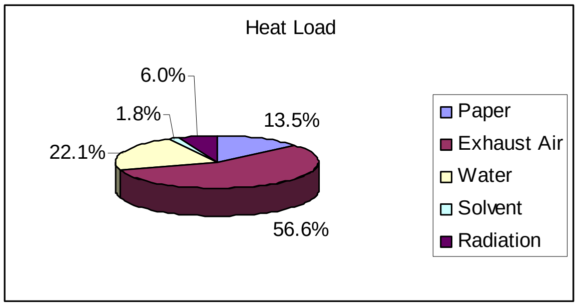


Fig. 4 – Heat Load Value Map (based on heat set printing application)

Grab the "low hanging fruit" first

According to U.S. Department of Energy, Industrial Technologies Program statistics, energy system integration and best practices opportunities, along with waste heat and energy recovery systems, account for more than 60% of the top R&D opportunities for energy savings.[3] The truth inherent in these statistics is apparent when we look for savings in the coating process drying/ curing function.

There are many approaches that can be taken to limit the energy used in the dryer. As suggested by our value-mapping exercise, most are focused on either reducing heat loss or exhaust air volume.

Some approaches can be low cost efforts that involve mostly labor and material expenditures (i.e. best practices oriented efforts). These include; sealing leakage points (doors and windows etc.), re-insulating hot spots, adjusting air flow balancing dampers, properly maintaining heat sources, greasing roller bearings and aligning rolls.

Often, simply analyzing and modeling your process requirements can lead to energy reduction opportunities by insuring that your thermal resources are applied proportionately to your raw material and end product drying requirements. For example, by instituting recipe management type operating procedures, you can insure that dryer zone temperatures, line speeds, and nozzle impingement velocities are optimized to the specific needs of each product, thereby ensuring that only the energy required to produce a quality product is expended. It is worth mentioning, that sometimes becoming "more efficient" may mean raising operating temperature rather than lowering it (i.e. efficiency is a measure of energy input per unit of production output, therefore, if a small increase in temperature results in a large increase in throughput, this may well result in an overall lower cost product).

Other energy saving or efficiency improving approaches may involve modest capital investments; such as automating air flow control dampers, adding exhaust recirculation loops, or adding web IR sensors to control burner output. These latter suggestions can be more expensive if the process is not already equipped with PLC controls.

The installation of monitoring, metering and database collection type systems can allow plants to collect and analyze energy data from their processes. Armed with such data, energy saving maintenance and standard operating procedures can be implemented. For instance, many converting processes have machine uptime in the 50-80% range. Something as simple as knowing when to bring processes on and off-line can save thousands of dollars of energy otherwise wasted as processes idle needlessly, with dryers maintaining set point temperature, exhausting hot air to atmosphere and forcing building Make-up-Air systems to "high-fire" in the winter months or to maximum cooling conditions on hot summer days.

Finally, there are a number of technology-based opportunities for improving dryer/process efficiency that involve more significant capital investments. A few of the more common energy saving solutions are covered below.

In water-based applications (particularly applications involving paper or other temperature tolerant substrates), dryer exhaust temperatures of 275 – 400˚F are not uncommon. Adding a heat exchanger (Fig. 5) to the exhaust air in order to preheat the dryer make-up air will often provide a financial payback of less than two years on the investment.

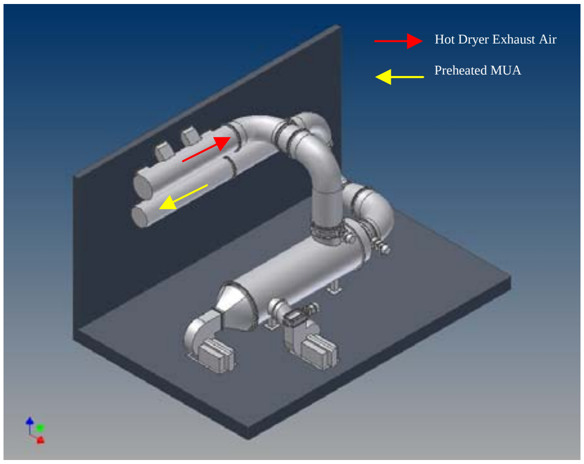


Fig 5. Energy Recovery from Dryer Exhaust

Another water-based process energy-saving solution involves the installation of humidity sensors in the process exhaust air stream/s. Using feedback from this device, an operator can adjust the exhaust volume control damper/s to maintain a humidity level that insures both full drying of the product and a minimum exhaust rate (Fig. 6). With feedback to a PLC and the addition of modulating damper/s this type of system can run in a closed-loop mode, eliminating operator intervention.

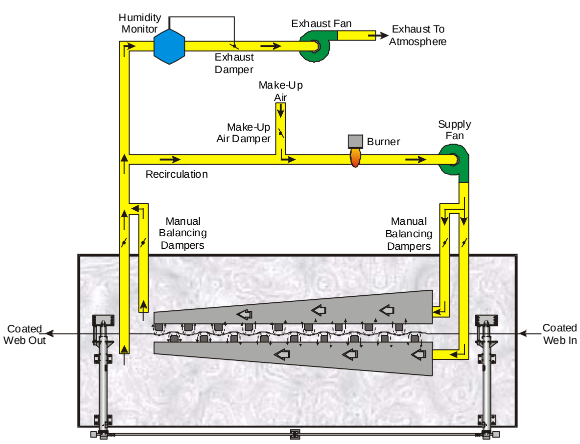


Fig. 6 – Humidity Control of Exhaust Volume

For solvent-based drying systems, this same concept of exhaust volume reduction can be achieved by substituting LEL monitors for humidity controls (Fig. 7).

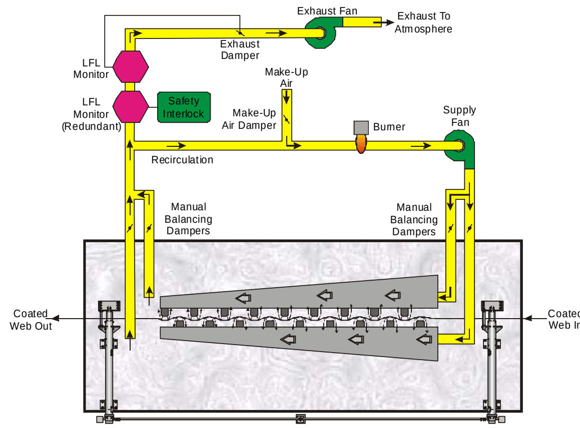
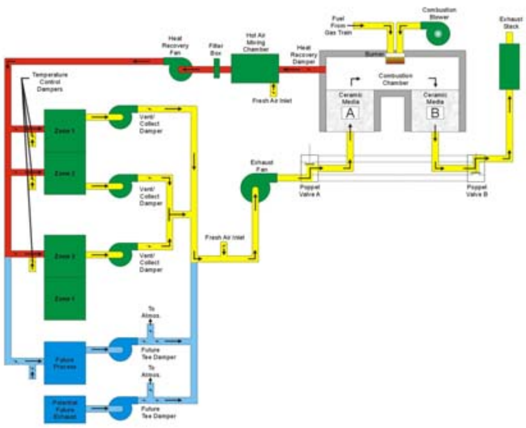
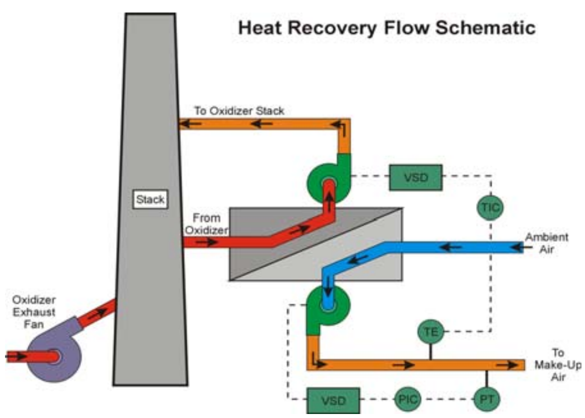


Fig. 7. LEL Control of Exhaust Volume

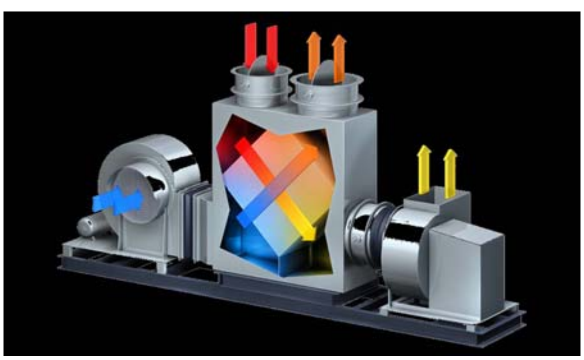
Solvent-based converters also have some different opportunities available to “close the energy loop” through the installation of oxidizer secondary heat recovery technologies. Solvent-based coating processes are typically required by USEPA regulations to exhaust into some form of thermal oxidation system. These pollution control devices typically use high temperature (1500 - 1600˚F or more) to convert or oxidize the solvent (hydrocarbon) laden exhaust air stream to the products of combustion CO_2 and H_2O. The oxidizer then exhausts the hot clean air to atmosphere. Depending upon the oxidizer design and the amount of solvent in the process exhaust, there is often excess energy released in the oxidation process that can be used for secondary heat recovery. Heat recovery can then be accomplished in two different ways; heat can be extracted from the exhaust stack, or directly from the combustion chamber. Several types of secondary heat recovery technology can be used in conjunction with thermal oxidizer systems; direct air, indirect air-to-air, air-to-liquid, and air-to-steam are the most commonly used technologies. Depending on the application, the thermal oxidizer can often provide all the heat necessary for the process dryers, eliminating the need for burner systems or electrical induction heating coil systems. Sometimes, there is still energy leftover for other process and/or building heating or cooling requirements. Some examples of secondary heat recovery schemes are shown below in Fig. 8 below.



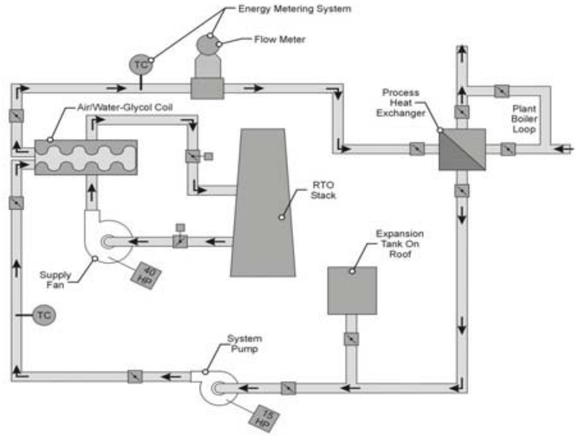
Direct Air Heat Recovery – Combustion chamber air mixed is with fresh air and returned to process



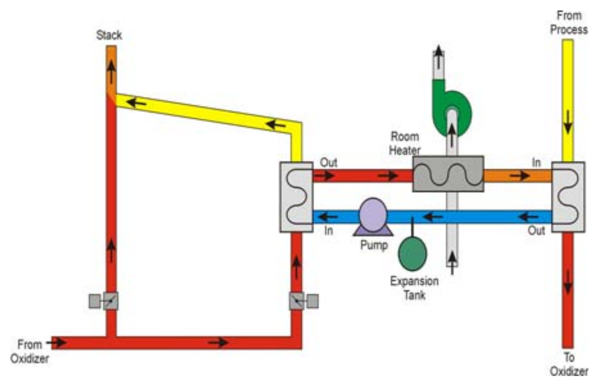
Indirect Air-to-Air Heat Recovery



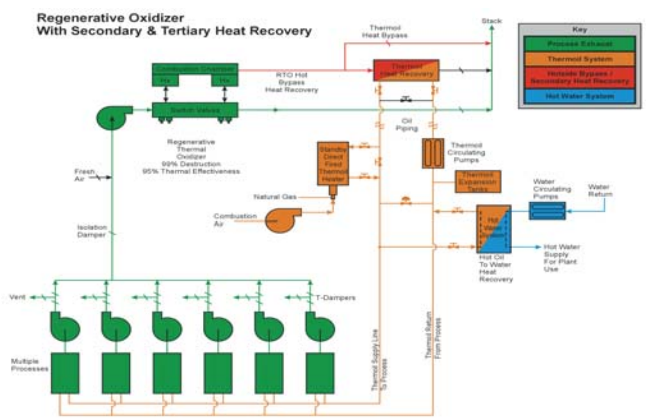
Cutaway View of Indirect Air-to-Air Heat Exchanger



Schematic of Water/Glycol System



Water/Glycol Economizer System



Air to Thermal Oil System

Fig. 8. – Various Heat Recovery Devices

Product Formulation Considerations

Beyond the obvious need to focus on the thermal drying technology component of the coating and laminating process, the energy efficiency of any given process can be significantly enhanced by reformulating the coatings so as to reduce the energy required to dry or cure the coating. For example, increasing the coating solution concentration can significantly reduce the drying load requirements of the product (Fig. 9). As an added benefit, concentrating solutions will reduce the energy consumed in the mixing process (Fig. 10). Also, where technically feasible, consider using easier drying solvents with slightly higher vapor pressure and lower heat of evaporation rates in order to speed up the drying process and reduce the energy required to remove the solvents (Fig. 11). In the case of flammable solvents, care must be taken to ensure process safety by proper management of the LEL within the zones of the dryer when changing solvents (reference NFPA Guidelines). In fact, anytime process changes are made, it is prudent to conduct a HAZOP to insure that margins of safety have not been compromised. Increasing solids concentrations can also save energy by reducing both the time and temperature required for good mixing (Fig. 12). Also, to further reduce mixing energy, a formulation can be mixed at a high concentration, and then diluted as required with in-line mixers prior to the coating application process.

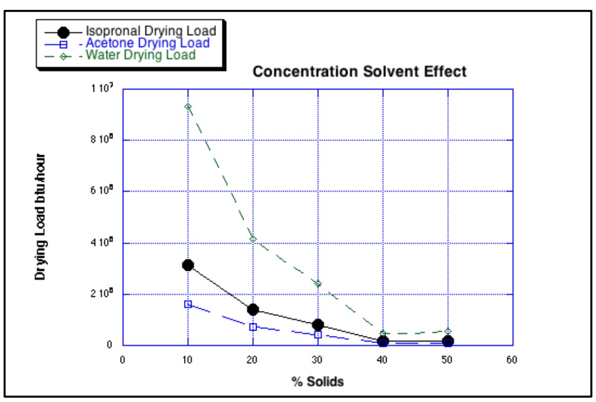


Fig. 9 – Effects of Solvent Concentration on Drying Load

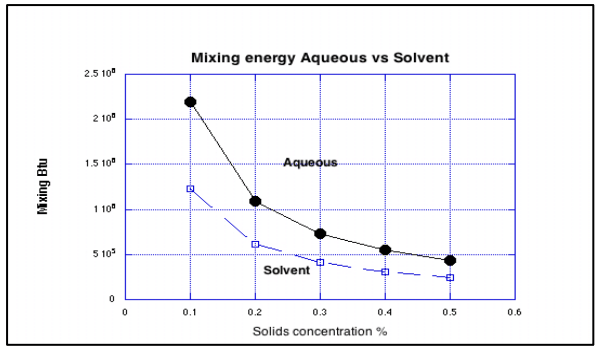


Fig. 10 – Impact of Concentration on Mixing Energy

Heat of Evaporation	
Solvent	**Btu/lb**
Acetone	**173**
Toluene	**151**
MEK	**186**
Isoproponol	**335**
Water	**1000**

Fig. 11 – Lower Heat of Evaporation Solvents can Reduce Drying Load

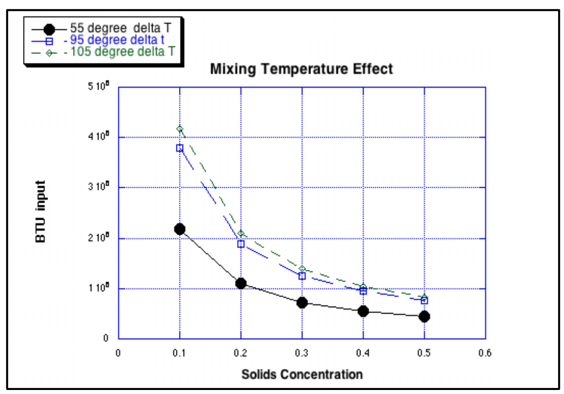


Fig. 12 – Mixing Temperature in Relation to Solution Concentration

100% Solids Coatings

Depending on your end product performance requirements, the use of solvent, and the need for thermal drying can be completely eliminated by using a 100% solids, hot melt, coating process. In this process a solid formulation is mixed and then heated so that it is a fluid with a low enough viscosity for easy application (Fig. 13). Typically, a cooling device (chilled rolls or an air cooling zone) is then used to reduce temperature and increase viscosity returning the coating to its solid state. As can be seen in the comparison chart below, the overall energy requirements are much lower for this process then for an evaporation process. It cannot be used for all products but should certainly be considered when possible.

Case 3 - Assumes hot melt application system with no thermal drying required.

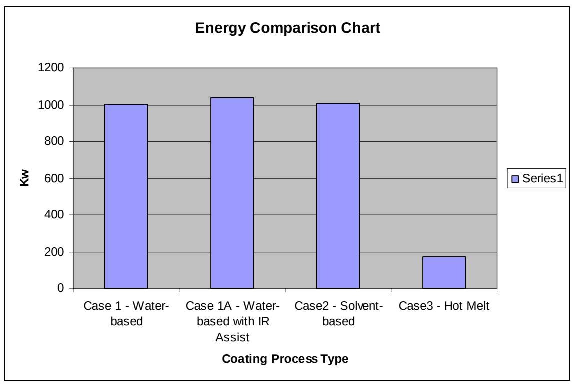


Fig. 13 – Energy Usage Comparison Chart

Other Energy Considerations

Another growing area of interest to energy conscious converters is the field of alternate energy and renewable energy resources. Some converters are already involved in projects aimed at reducing their energy costs, increasing their energy efficiency, reducing their "carbon footprints, and insuring uninterrupted availability of energy. For example, according to one published article found on the Paper Film and Foil Converter magazine website, Mohawk Fine Papers already purchases approximately 60% of their total electrical energy from wind-generated resources.[4] In the same October 2007 edition, PFFC also reported that Fujifilm was pursuing a project involving the use of methane gas from a local Greenwood, South Carolina community landfill. The gas will be piped into their boiler systems in order to "power approximately 40% of the facility's operations," reducing their greenhouse gas emissions while simultaneously reducing energy costs.[5] These and many companies are becoming less dependant upon local energy suppliers by installing water-powered generators, cogeneration equipment, and heat recovery systems that not only lower their energy costs but insure availability of energy even during high demand periods. One thing seems certain, over the next several decades, "creativity" and "cooperation" will be keywords for converting industry energy management personnel that are interested in capitalizing on new, clean and renewable energy resources such as wind, solar, geothermal, clean coal, biomass and fuel cells.

Summary

Today's forward-thinking converters are wisely focusing their attention on energy conservation and efficiency efforts as a means of reducing their overall cost of energy per unit of product output. They recognize that energy efficiency offers many product and process improvement opportunities that go beyond the common goal of cost reduction. Through the application of existing and new technologies along with the adoption of industry "best practices", converters are enjoying the benefits of taking a total energy management approach to their business operations.

References and Acknowledgements

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2007, Green Converting News – Article titled “Getting New Power”

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