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Process Intensification Module

MASTER OF ENERGY ENGINEERING (2011-2012)

Powder Coating Process Intensification - Applied Infrared Heating

Regarding painting and coating industries, there are two principal technologies that are the backbone for product finishing, liquid and powder coating technology. The former has been applied for more than two centuries, using both water and solvent based liquid to keep binding. Solvent-based coating systems are widely recognized for their outstanding chemicals which provide high gloss finishes and superior scratch resistance, for these reasons liquid coating are extensively used in the furniture and kitchen cabinet manufacturing business (Composite Panel Association, 2011). Another technology which has been used since the last thirty years is powder coating. It sprays free flow dry powders which were electrostatic charged in order to keep pre-adhesion, instead using solvent. After that, the part will be conveyed through a heat transfer chamber on a stationary or continuous process which will be control specific time at temperature in order to build a chemical crosslink between paint and surface (Pennisi, 2011).

In the age of environment crisis, powder coating plays a key role in the most finishing industries, and the growth of powder coatings has been dramatic during the last decade. The first and foremost reason for replacing liquid coatings by powder coatings is the environment issue. Although the liquid coating provides a large number of advantages, solvent-based liquid contains high Voltage Organic Compounds (VOCs) which harm to human health and brings about the environmental degradation (Creven, 1982); whereas, most modern powder formulations do not contains VOCs content. These compounds are of special concern because they photochemical react in sunlight to cause of smoke in the lower atmosphere and destroy protective ozone in the upper atmosphere (Talbert, 2003). Moreover, this problem became a big issue in global scale which interacts increasing the globe's surface.

Although the powder coating has more significant environmental friendly than the other, some authors (Bergek, 2011 and AkzoNobel, 1999) argue that this process uses a great deal of gases from a direct-frame gas burner for the purpose of convected heat generation which is typically used in pre-treatment process, drying oven and cure oven. Furthermore, the major problem of this process is wasting a great deal of heat from conduction through oven's shell and convection of hot air to surrounding environment, particularly hot airflow out from a cure oven which has to be controlled temperature up to 200°C (Bergek, 2011).With regard to these problems, PI methodology (12 Steps) will be used to identify the drawback of the process and improved by adopting intensify equipments as the following details.

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Step-1: Overview Whole Process

Regarding to conveyorised powder coating process, it can be divided in to four sections which are cleaning & pre-treatment, drying oven, powder box and cure oven as shown in Figure 1.1.

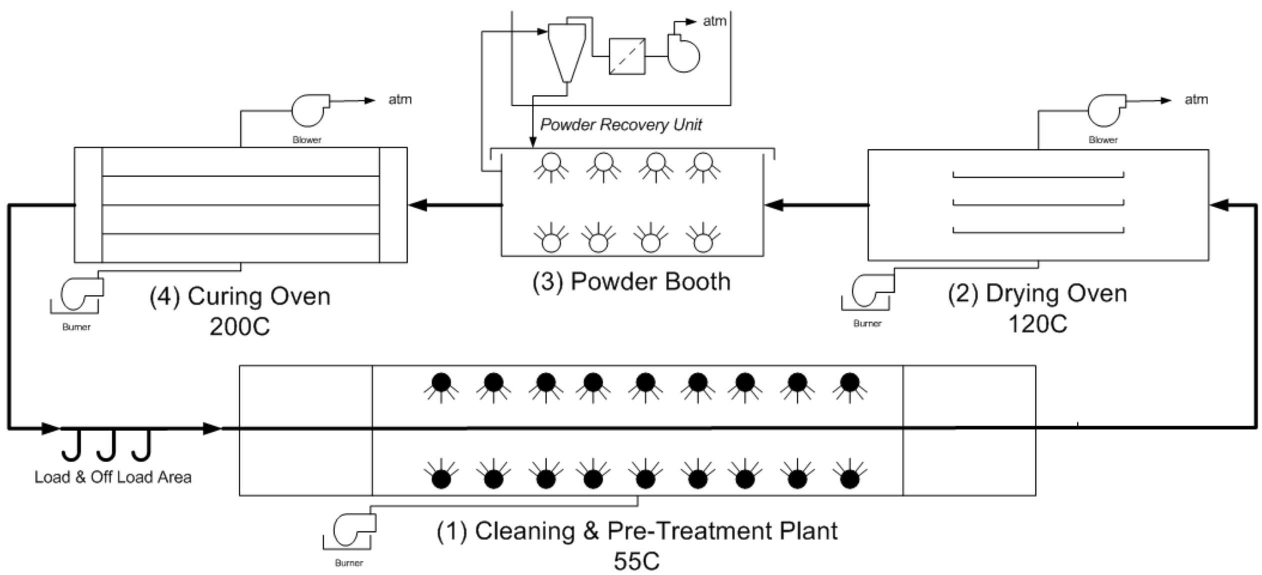

Figure 1.1 Powder Coat Plant Schematic Layout

<u>1.1) Cleaning and Phosphate Plant</u>

Powder coating is solvent free properties; pigments and resins are stuck on the surface through electrostatic force until heated and fused into a smooth coating in a curing oven. Therefore, parts' surface must be clean and carefully free any type of oil or grease contamination from especially metallic finishing surface; otherwise, coating quality will be declined. This enhancement can be done by two process, mechanical and chemical cleaning.

- *Mechanical cleaning* included the method likes scratch brushing and sand blasting. This process plays significant to remove surface impurities, but coating must be done immediately; otherwise, corrosion will be occurred very fast.
- *Chemical cleaning* used for removal of dirt, oil and grease, and the oxidation products. It can be applied by wiping, spraying or dipping. Moreover, type of chemical depends upon parts' material; for instant, phophating can be used both aluminum and mild-steel (Mitsubishi Systems, 2011).

With regard to general cleaning and pre-treatment sequence, mechanical cleaning will be done before conduct the part into cleaning and pretreatment tunnel which was divided into many zones depended on its functions. First of all, heating zone consists of spray nozzles and holding tank. In this zone, hot solutions in holding tank were heated by fuel burner, typically retain temperature 55˚C (Bergek, 2011), then will be sprayed onto the part, and finally the liquid will be returned into holding tank for recirculation and filtration. Thereafter, the parts were conduct into cold and hot rinses zone which spray nozzles also installed by mean using mechanical force to remove contaminated debris from surface before move to drying oven respectively (RDM Engineering, 1996).

1.2) Drying and Curing Ovens

Drying and curing ovens are key equipments for powder coating process. With regard to *drying oven*, it must retain temperature about 120˚C which is conventionally generated from directed flame gas burner and uses LPG as fuel. It aims to evaporate all remaining water from pre-treatment process. A *curing oven* located at the last step of process after powder was sprayed on the surface, oven's characteristic is the same as drying oven but has significant the highest temperature about 200˚C and may go up to 250˚C in some type of powder. This temperature range leads to transform powder pigment to smooth finishing surface, but these parts must be held in the particular temperature not lower than specified time which each project is difference depending on paining and product characteristics such as colour, hanger density, material thickness and shape (TW Gema, 2007).

1.3) Powder Booth

The powder booth is a station objected for applying powder to object. There are two types of powder booth, *fluidized bed process* and *electrostatic spray process*. The former suitable for a large work-piece such as pipeline and valve, attached by electrically charged cloud of powder inside powder box. Regarding this report, electrostatic spray process is taken into consideration which the powder is typically electrically charged and sprayed through spray gun onto work pieces and then overspray powder will be recovered and reused in the system. Powder spray system typically consists of three sub-components such as electrostatic charging & spraying, powder box and powder recovery system as shown in Figure 1.2 and 1.3.

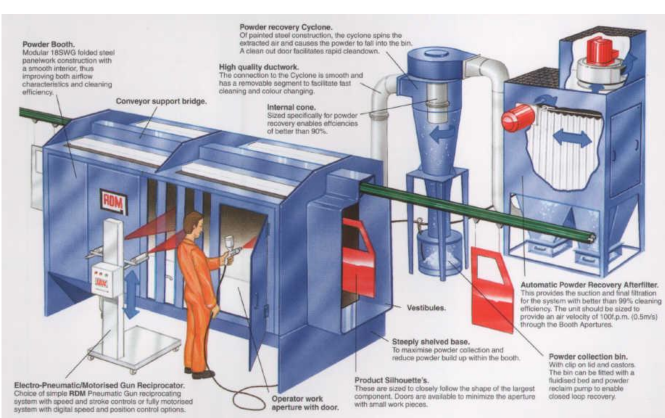

Figure 1.2 Powder Booth Schematic Layout
(www. http://rdmengineering.co.uk)

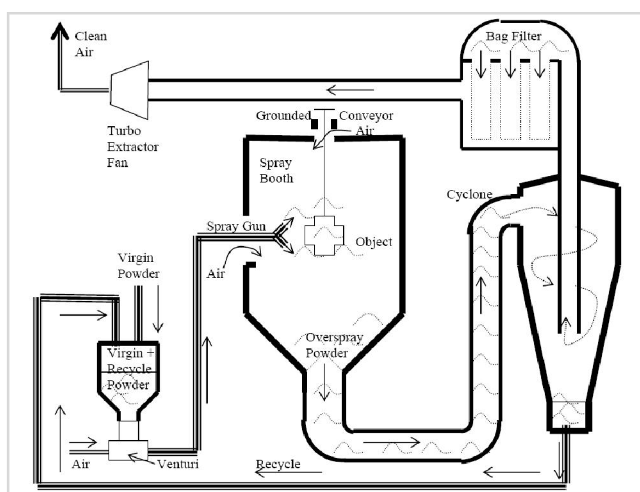

Figure 1.3 Powder Auto-Recycling system,
AkzoNobel (1999)

1.3.1 Spayed Gun

Electrostatic sprayed gun apply electrostatic charged into powder particles which lead deposition and adhering on the part surface which connected to ground. The powder was typically discharged with velocity 60 m/s (AkzoNobel, 1999) and over sprayed powder will be recovered.

1.3.2 Powder overspray recovery system

The objective of powder-recovery system is to collect overspray powder, recycle into system and also ensure that powder ventilated away from operators. The recovery process is driven by an exhaust air ventilator which maintains velocity 0.4-0.5 m/s which low enough to interfere the powder leaving from spray gun (AkzoNobel, 1999). Cyclone connected to booth and fan, the entrance tangentially the air/powder mixture flow direction which brings about a centrifugal force on the particles from rotary motion. The large particles will fall into bottoms while lighter particles will suspend in air stream and then will be collected by filter at exist before clean air exhaust to atmosphere.

Step-2: Analyze the Business and Process Driver

2.1) Plant flexibility – the process has ability to handle different products and change from one to another rapidly.

- *Curing oven* can accommodate various products, particularly thickness material which requires more time to heat it up than the others.
- *Powder recovery system* can support painting the different colours.

2.2) Reduce energy consumption and plant size can be achieved by combining electrically enhanced system into process which can drive surface temperature up rapidly.

2.3) Enhanced energy efficiency, via reduce rate of heat release from ovens and also recovery heat from curing and drying oven and exchange heat to entrance oven air through compacted heat exchangers.

2.4) Improve safety, via reduce heat loss from conducting through oven shell and convection at entrance and exist of the oven. High temperature air and object effects human skin which can lead to burnt or destroy tissue; moreover, working in relatively high temperature environment can also bring about the death in some case.

2.5) Environmental friendly – Although powder coating process does not emit VOCs which harm to human and environment, there are still CO_2 emission discharged during air-gas combustion process in drying and curing oven. CO_2 has significant to increasing the globe temperature and climate change.

2.6) Cost reduction; via enhance powder recovery system which most of overspray powder can be reused.

Step-3: Examine PI 'Blockers' and Identify Rate Limiting Factors

3.1) Limited by the cure cycle, the parts must be retained at high degrees of temperature in curing oven (200°C) within specified time, typically 10-30 minutes; otherwise, the powder will not crosslink properly as a result include orange peel and lack of adhesion.

In practical, high thickness parts such as steel beam tend to has longer holding time than flat metal sheet because *Hot-Air Oven*, the parts are heated by hot air and it conduct heat into coating, so it took a long time to heat the parts up to specified temperature as shown in Figure 2.1. This temperature profile stated that curing process took a great deal of time (15 minutes) to heat the parts while the painting requires only short period time (9 minutes).

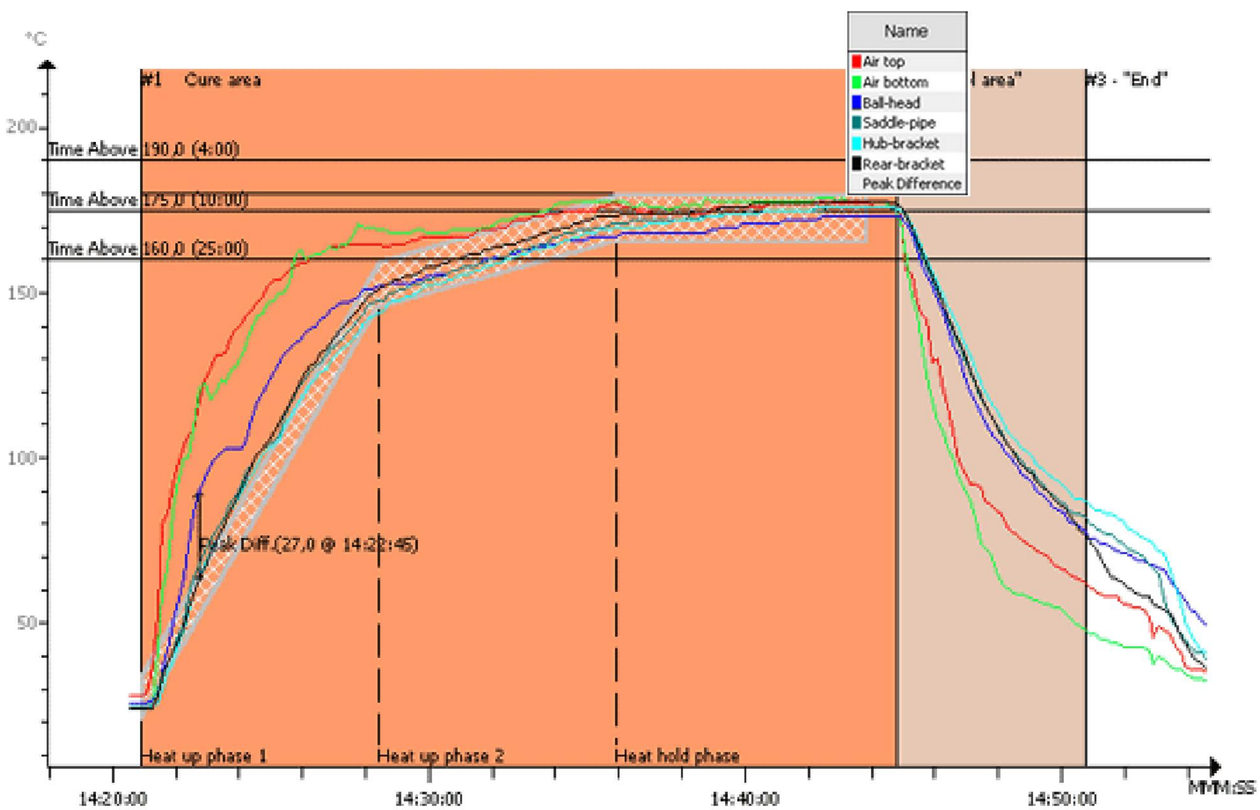

Figure 2.1 Temperature profile of curing a bicycle frame

(http://www.powder-cure.com)

Therefore, the line speed and production rate are limited by cure cycle time but the part can be stayed for longer period than curing time without effect on finishing quality and colour.

3.2) Dimension of the oven influences the duration of warm-up. With regard to size of the oven, although large oven suitable for large size products, it contains more air than narrow pathway oven, so it consume a great deal of energy to start oven up and took longer time to heat the air up than the other, average 30 minutes.

3.3) Regarding the recovery system, the lines that have a high percentage of particles (<10μ), recovery efficiency was reduced as low as 85% due to small particles still stuck on air current and run into last stage filter, instead drop into bottom of a cyclone. Moreover, powder booth and cyclone material typically made from stainless steel and some made from galvanized steel; however, its metallic wall permit electrostatically charged, so powder tend to stuck on metallic and took a long time to clean when the process need to change colours.

Step-4: Generate Design Concept

Regarding the curing oven, it must me design to have rapid heat up rate, especially for radical thickness part and high density hanger. In the same time, oven size must be designed to have smallest size or can adjust according to the part dimension in order to optimized oven warm up period. *Electric enhancement method* was chosen to enhance heat transfers in conventional curing oven which can delivery intensify energy directly to inside of the objects through radiation with minimized heat loss, rather than having to be conducted from surface of the body; moreover, it also provides flexibility, ease of control and faster product throughput (David, Colin and Adam, 2008:p65-70).

In term of energy efficiency, a great deal of hot convection heat from heated air in the curing and drying oven discharged to atmosphere. These heat will be recovered and exchanged to the other equipment through CHEs discharged to atmosphere.

With regard to powder recovery system, friction reduction in powder booth and intensify powder recovery for small particles (<10μ) are taken into consideration. The general design concept of powder box friction reduction can be achieved by using non-electrical conduction such as plastic or glass to build enclosure of powder box instead using metallic material which powder tend to be stuck on its surface.

Step-5: Analyze the Design Concepts

The new design for powder coating plant can be divided into three sections shown in Figure 5.1.

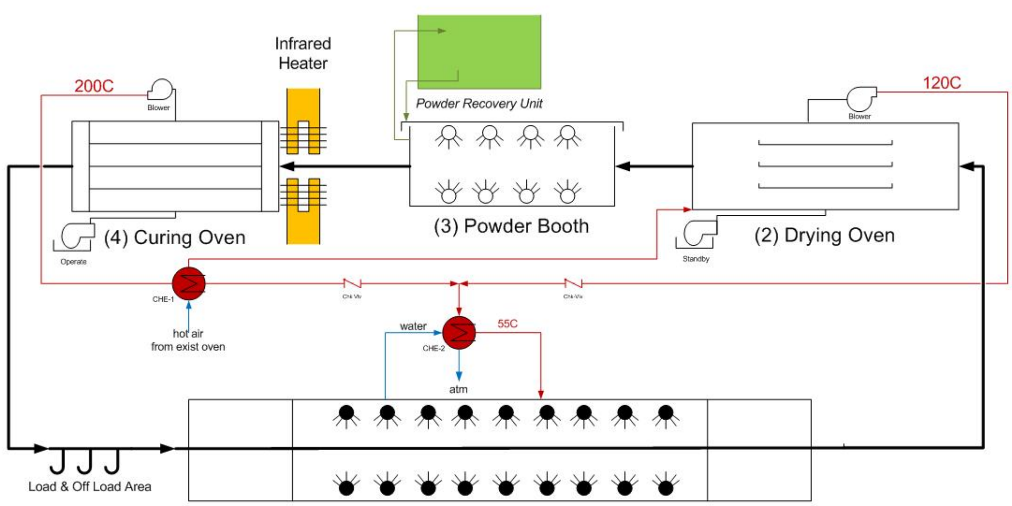

Figure 5.1 Conceptual Designs for new Powder Coating Plant

- First of all, enhancement and flexibility of production by using electric infrared heater adopting with conventional hot-air system.
- The second section is that CHEs will be chosen to improve energy efficiency and reduce total energy consumption of system through hot-air recovery system. (*extended study*)
- The final section interest intensify powder absorption regarding small particles powder, rotating in a cyclone and mop fan will be taken into consideration for enhance absorbed surface in order to intensify powder recovery system. (*extended study*)

This report regards only unit operation which curing oven which is the bottle neck of powder coating process which line speed limited by dwell curing time. High intensity infrared can be used to ramp up the object temperature which the energy is taken directly to inside of the objects being heated, rather than having to be conducted from the surface (Reay, 2008). This energy transported vie electromagnetic wave which typically short, medium and long wave were adopted to the heating industry. When the higher emitter temperature, shorter wave length will be generated.

Table 1: Properties of Infrared emitter, different wave length (BKG Finishing Systems)

Wave Length	**Temperature (°C)**	**Media**
Short wave (0.78 – 2.0 µm)	3,000 - 1,100	Fast respond on-off
Medium wave (2 – 5 µm)	1,100 - 650	Still controllable with reduced respond.
Long wave (5 µm – 1 mm)	Under 650	Similar to hot air oven, very slow respond.

Moreover, heating by radiation seem to be the most effective way because the Infrared oven do not require heating air to heat product, but the product will be heated directly as a result of IR oven can bring the product just short a require cure time and reached to specific temperature rapidly as show in Figure 5.2 below.

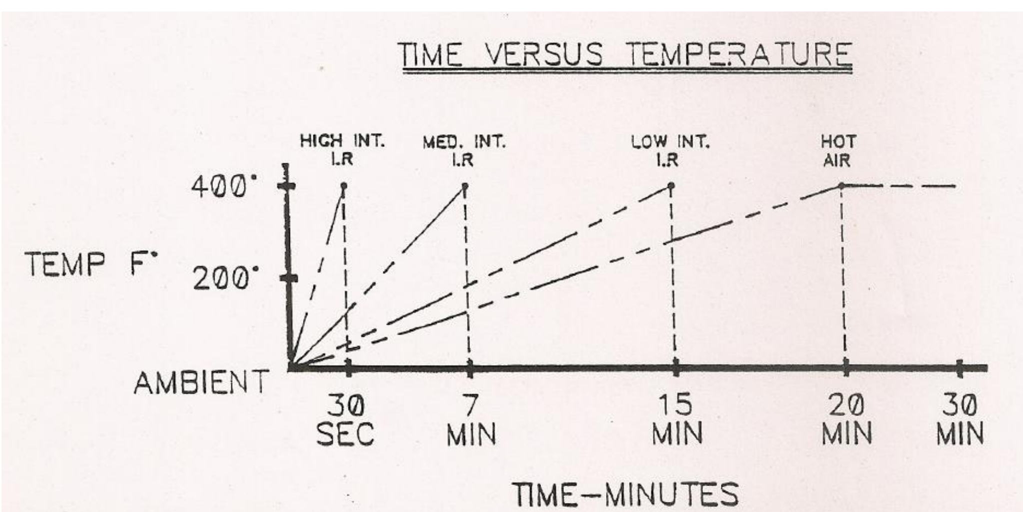

Figure 5.2 Comparison of product heat up rate of Short/Medium/Long wave IR and Hot air (BKG Finishing Systems)

From the graph, it stated that high intensity infrared (short wave length) tends to be the fastest heat up rate which faster than conventional system, hot air about 40 folds. Moreover, the infrared emitter can also be enhanced by using primary and secondary reflector. With regard to improvement of conventional process, infrared emitters can be adopted into system *[1]Pure infrared oven* or *[2]Combined infrared (IR + Convection) oven* which IR used to boost temperature up and hot air used to hold and ensure product temperature, Figure 5.3 and 5.4.

Figure 5.3 Infrared (IR) curing oven

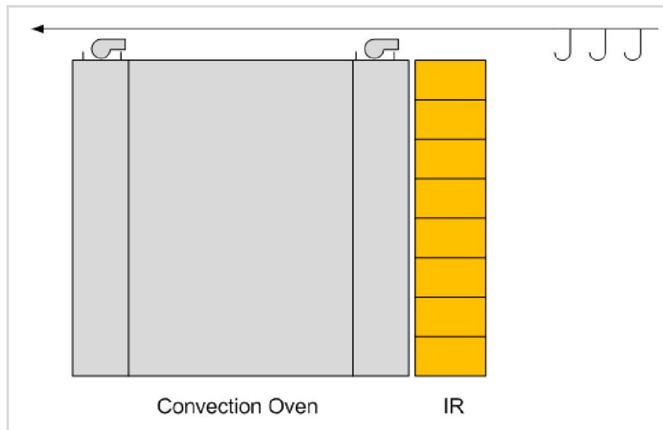

Figure 5.4 Combination oven (Convection + IR)

With regard to photocatalysis, *[3]Ultraviolet-cured powder coating* can also be used to enhance curing process as it can also be categorized as electric enhancement method. Regarding the principle of UV, it has wave length between 10nm – 0.39µm. UV radiation seems dramatically enhance curing cycle which the object can be cured in seconds instead in minutes likes the other systems. For example, the combination between IR emitter and UV lamps, powder will be melted under IR heater then cured in 5-10 seconds by UV lamps as the diagram shown in Figure 5.5. Moreover, another advantage of UV curing is that operating within low temperature curable powder as low as 80°C (Air force material command, 2008).

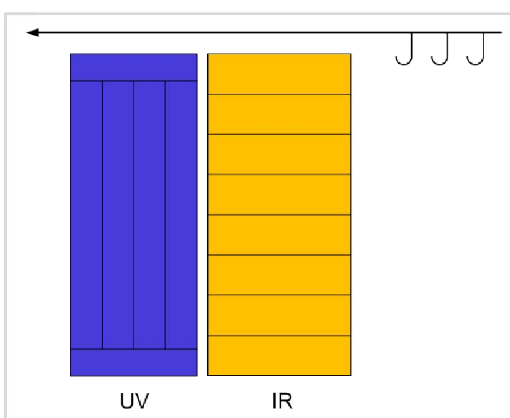

Figure 5.5 Combination oven (UV + IR)

Step-6: Select the most suitable equipment

Economy

The total capital cost for improvement conventional system consists of equipment cost, operational cost, and maintenance cost. Conventional system has the greatest advantage on operational cost because it typically uses gas as main energy sources which gas price is typically less expensive than electricity. However, it tends to has high maintenance cost from maintenance rotating machines such as gas burners and blowers which moving part should be always looked after and lubricated. On the other side, electrical system (UV and IR) tends to has benefit on zero maintenance cost and also labor cost reduction. Although both seem to be high operational cost as high cost of electricity, the system can be designed to be energy efficiency; for instance, automatic switch emitter on/off controller which permit the lamps on only when the product pass through. This control can be done perfectly because IR/UV emitter characteristic has fast respond on/off time within 1 second.

Process Flexibility & Energy Efficiency

With regard to plant size, intensified heat transfer by electric enhancement method tends to be the most effective in term of space usage. Moreover, adopting infrared emitter into conventional or combined IR/UV can lead the process more flexible which even high thickness part that act as a heat sink during processing such as pipe, I-beam and engine block or high density hanger can be cured rapidly. However, the disadvantage of radiated method is undercure when the object has highly complex shape due to radiation cannot transfer energy through shade area stated in Figure 6.1.

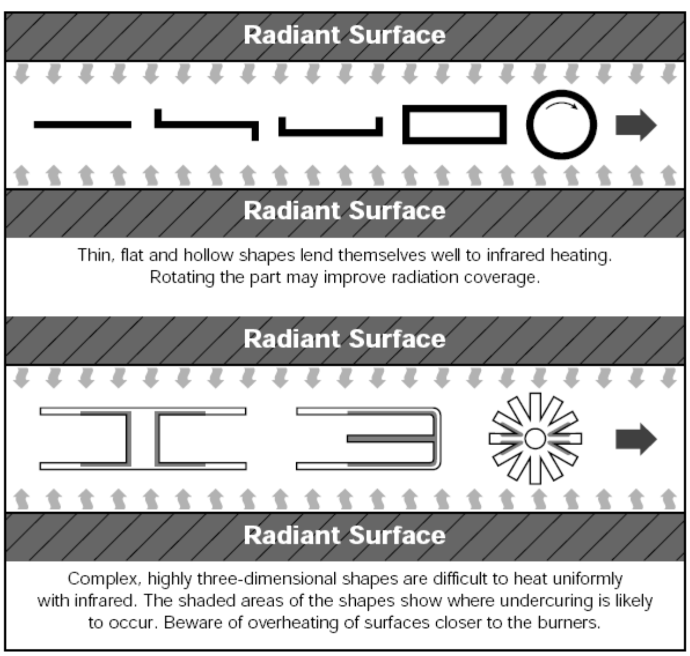

Figure 6.1 Suitable product configurations for IR heating (Eclipes Combustion)

With regard to efficiency of particular equipments, electric heater can operate within efficiency up to 90% (efficiency = energy emitted / energy consumed), but gas burner tends to be low efficiency than the other about 40-60%. In term of process temperature, convectional oven has significant leak of hot air at the entrance and exist of the ovens; however, electric heater did not heat air but transfer energy directly onto surface object; therefore these tend to be low heat loss to atmosphere especially UV heater which has low temperature curable powder as low as 80°C.

Safety

According process driver description, high temperature oven and hot-air leak can harm to operator; for instance, skin burnt and hot climate can also cause of the death. However, UV oven seems to provide advantage more than convection and IR process because its characteristic is operation within low temperature. However, high insensitive of UV light are hazardous to the eyes which can cause of welder's flash and also lead to cancer risk. In the same way, high intensity infrared radiation may affect the eyes and resulting in damaging or even blinding the user. Therefore, operator must wear goggles when operating IR and UV related process.

Environment

Using gas as energy source in conventional process tend to increase CO_2 emission in atmosphere, contributed to climate change crisis. However, every conceptual seem to be related to this problem because even gas combustion process or electrical generation emit green house gases onto atmosphere.

Regarding the business driver, selecting the most suitable process can be done by taken into consideration the criterion such as safety & health , environment effect, plant flexibility, enhanced production rate, economy (install, operate and maintenance cost) and optimized space usage of the three conceptual shown in Figure 6.2 below. The decision can be done according to weight factor and scale as show in Table-2 and 3.

Figure 6.2 from left to right, IR oven, Combined IR/Convection oven and Combined IR/UV oven

Table-2: Score description

5-Point Scale	Description
1	Inadequate solution
2	Weak
3	Satisfactory
4	Good
5	Excellent

Table-3: Result of decided the most suitable conceptual

Criteria	Weight Factor	IR		IR + Convection		IR + UV	
		Score	Rating	Score	Rating	Score	Rating
Safety & Health	0.3	3	0.9	5	1.5	2	0.6
Environmental concern	0.2	4	0.8	3	0.6	4	0.8
Plant Flexibility	0.2	4	0.8	4	0.8	5	1
Production rate	0.1	4	0.4	3	0.3	5	0.5
Economy	0.1	4	0.4	5	0.5	3	0.3
Foot Print	0.1	5	0.5	4	0.4	5	0.5
			3.8		4.1		3.7

Step-7: Make the Final Decision

For high thickness and complex shape objects such as I-beam, engine block and automotive parts, the combination of electrical radiant heater and convection oven has significant enhance process as the drawing of this system shown in Figure 7.1.

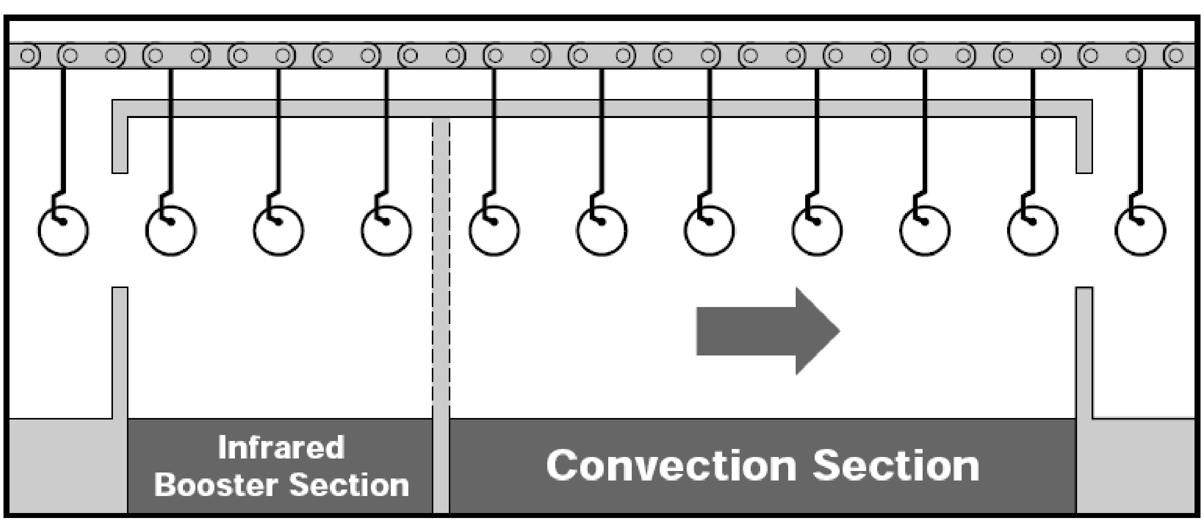

Figure 7.1 convection oven with infrared booster section