Topical Report

Gas IR Application in Paper Drying Process

Prepared by:
SS Energy Environmental International, Inc.
Rockford, Illinois

Gas Research Institute
Distribution and End Use Business Unit
May 1969
GAS IR APPLICATION IN PAPER DRYING PROCESS

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Majority of gas IR heaters had been applied to pre-dryer/preheating and coating drying and curing applications. However, some mills have used these burners in presses as well as to accelerate the evaporation rate for a faster machine speed. The major types of IR burners used frequently in paper/coating drying are, ported metal or ceramic tiles with reverberating screen, ceramic or metal fiber matrix, and impingement type.

This report provides the current technology status that influences the drying process, particularly as an add-on to the steam drum dryers. In addition, most widely used gas IR heaters and their contribution to the paper drying process are described with some specific applications. This report can provide LDC's agent and engineering service companies to recommend the appropriate manufacturers and their equipment for achieving the best results.
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Executive Summary

The purpose of this report is to highlight the utilization of gas IR heaters in a pulp and paper drying process. The report provides the current technology status that influences the drying process, particularly as an add-on to the steam drum dryers. In addition, most widely used gas IR heaters and their contribution to the paper drying process are described with some specific applications. This report can provide LDC’s agent and engineering service companies to recommend the appropriate manufacturers and their equipment for achieving the best results.

The basic components of a paper machine include (1) the stock inlet (flowspread) which distributes the paper making fibers uniformly across the machine. (2) The pressurized headbox, which distributes the paper stock onto the moving forming wire. (3) The Fourdrinier wire that forms the fibers into a sheet and enables the furnish to drain and dewater. (4) The press section, where additional water is removed and the fiber web is consolidated. (5) The dryer section, which removes most of the remaining water by evaporation. (6) The calender section where the sheet is pressed between metal rolls to reduce thickness and smooth the surface. (7) The reel, which winds the dried, calendered paper onto itself. Many papers are coated with suitable formulations to provide improved gloss, slickness, color, printing detail and brilliance.

The more common paper and board grades are: (1) Printing grades that include newsprint, catalog paper, rotogravure paper, publication paper, banknote and document paper, bond and ledger paper, and stationery paper. (2) Industrial grades including bag paper, linerboard, corrugating medium, construction paper, greaseproof paper, and glassine. (3) Tissues including sanitary tissues, condenser tissue, toweling, and wrapping tissue.

Majority of gas IR burners had been applied to pre-dryer/preheating and coating drying and curing applications. However, some mills have used these burners in presses as well as to accelerate the evaporation rate for a faster machine speed. The major types of IR burners used frequently in paper/coating drying are, ported metal or ceramic tiles with reverberating screen, ceramic or metal fiber matrix, and impingement type.
Gas IR heaters provide an intense heating source for faster evaporation rates. The installation of gas IR heaters is economical, convenient, have a smaller footprint and lower maintenance. The heat-up times of a few seconds allows the IR heater to start the heating almost instantaneously while the cool-down time of one second reduces fire hazards or injuries in case of an emergency. The various gas IR heaters, as provided by the various OEM's, used in paper drying are mentioned in Chapter VII. Gas IR heaters have shown to improve the drying capacity of the paper drying machine by 10%-15% and so are crucial in increasing productivity of the paper machine.

The effect of using gas IR heaters at different locations in the paper drying machine, determines the extent to which the drying performance can be improved. The application of IR heaters in a Fourdrinier machine, at various locations, is shown in Figure 1.

Conventional steam methods are sometimes used to dry coatings but, more often, other methods are used to avoid disturbing the coating film. The most commonly employed methods are hot air impingement and infrared drying. Gas-fired infrared emitters provide a compact, high-intensity heat source that transfers its energy without physical contact. Since the infrared radiation unit only supplies the heat, air must be provided to carry away the moisture that is evaporated from the coating. Some drying units, therefore, combine both infrared and air impingement dryers. Newer emitter surfaces are able to dissipate heat within seconds, making their cool-down and heat-up rates almost comparable to those in electric systems. Consequently, contemporary gas IR systems can be placed closer to the sheet surface, thereby allowing more energy to be applied to the web with a resultant increase in the drying rate.

The determining factors while choosing between the two systems are (1) The objective of the application, and (2) the cost and availability of the energy. Typical infrared applications include (1) Base-sheet profiling just prior to the coater for which electric IR systems are exclusively used. (2) Coating drying for high-intensity coating drying immediately following the coater for which either gas or electric IR systems can be used. (3) Moisture profiling prior to the reel which is done with electric IR heating.
CHAPTER I

Introduction

In a paper manufacturing process, pulp and paper-drying process consumes significant amount of energy per ton of paper produced. Steam drum dryers are mostly used for thermal drying of paper. However other means are being utilized to supplement the steam drying of paper because over a number of years of operation the paper machines go through an aging process, which includes wear and tear of the drum due to corrosion, and erosion induced by steam and surrounding contamination. This condition reduces their performance and demands heavy operating and maintenance costs. Paper drying machines are extremely capital intensive, therefore it is difficult to replace them.

In a recent study it was found that nearly 90% of paperboard mills at weights over 30lb/1000ft² and about 84% of paper manufacturers at weights over 50lb/3000ft² become dependent on their drying capacity for improving the paper manufacturing productivity. The alternative to accomplish an increase in productivity is by adding gas IR heaters to the existing steam drum dryers. In fact, steam drum dryers when combined with gas IR heaters, have resulted in a 10-15% increase in productivity, depending upon the gas IR heaters and their locations in the paper drying process.

The conventional steam dryers, used in the paper making machines, might need replacement by gas IR burners in the occurrence of one of the following scenarios, to improve the paper drying performance.

1. Due to loss of mechanical strength, the drum becomes unable to accept the required high pressure and hence meeting the design performance.

2. Due to the aging of the paper drying equipment, paper mills have to consider buying new steam drums to replace old ones to meet the production rate, or adding a new drum dryer to the old dryers requires additional space which is hard to find in a mill.
3. Other concerns with paper mills is global competition from Asian, European and Latin countries. In this situation, increased productivity from the existing machine is the most logical thing to consider. One of the means to exceed or meet the market challenge is the use of gas IR heaters as add on to the steam dryers.

Gas IR burners have several economical, heating, installation and maintenance benefits over conventional drying equipment and so are used widely in hot pressing, preheating, coating drying and moisture profiling. Although, gas IR heaters have been applied in paper industry for decades, there are still concerns as to which type of gas IR burners are most appropriate. Reasons are often due to inadequate technical information that can help understand the individual burner performance and their longevity.

One of the often raised questions is related to the inability of achieving rapid thermal response from the gas IR heaters. For all practical purposes, this concern has been eliminated by newly developed ceramic or metal fiber matrix emitters, which reach their operating temperatures and cool down temperatures to ambient condition in a few seconds. In addition, these burners provide higher heat flux and uniform temperature across the paper sheet, which are critical in maintaining uniform moisture gradient and thus good quality of paper. There are several different types of gas IR burners available in the market. Choosing one for drying of paper depends upon the individual paper manufacturers and their specific needs.

Three major gas IR burners applied in a paper/coating drying process are,
1. Ported metal or ceramic tiles with reverberating screen.
2. Ceramic or metal fiber matrix, and
3. Impingement type.

Each type of burner has unique characteristics, details are given in Chapter VII. Type(1) and type(2) have been used extensively in pre-dryer section and in coating drying and curing, while type(3) has been extensively used in coating curing where heat penetration to the coating and subsequent removal of vapors are quite critical in achieving better quality of the coated paper.
The main focus of this report is to describe the role of gas infrared burners in a paper drying process, by collecting and analyzing the information from various sources including but not limited to the gas IR manufacturer, published technical and commercial literature, private communication with the paper machine manufacturers.

Technical facts should allow gas utilities, paper mills operators and engineering service companies to examine the effect of different gas IR heaters role in different parts of a paper drying process and subsequently choose the suitable IR heaters that would meet the users expectations.
CHAPTER II

Paper Manufacturing Process

It is a multi-step process and includes several steps before cellulosic fibers become a paper sheet. Paper is produced using three different types of machines, which are as follows,

1. The Fourdrinier machine is applied to a wide variety of paper grades.
2. The Yankee drying machine is used mainly in making tissue paper.
3. The Cylinder machine is used largely to make recycled paper.

The Fourdrinier machine, which is used in producing a variety of paper grades, is chosen for our technical discussion.

In a Fourdrinier paper machine, see figure 1, the pulp containing 60% or more water is deposited from a reservoir, called a headbox, on a porous wire mesh belt. As the belt moves away from the headbox, much of the water drains out of the pulp and through the belt. Vacuum boxes are often used to assist the extraction process.

The pulp sheet is transferred to a continuous belt made of felt. The felt supports the pulp until it is sufficiently dense and strong to be self-supporting. The web and felt then pass through the press section that consists of a set of rolls that squeeze more water out of the pulp. The web leaving the press contains about 50% water. It is transported over large steam-heated drums for drying. It may also pass through additional stages called calendering and coating.

Due to predominant use of Fourdrinier machine, we have described below typical steps involved in this type of machine.
Figure 1: A schematic diagram of a Fourdrinier paper machine with possible IR burner locations.
The basic components of a Fourdrinier paper machine are:

1. The **stock inlet (flowspreader)** which distributes the paper making fibers uniformly across the machine from back to front.
2. The **headbox** is a pressurized flow-box that distributes the paper stock onto the moving forming wire.
3. The **Fourdrinier** wire is an endless moving wire that forms the fibers into a sheet and enables the furnish to drain by gravity and de-water by suction.
4. The **press section** is the part where the sheet is conveyed through a series of presses where additional water is removed and the fiber web is consolidated.
5. The **dryer section** removes most of the remaining water by evaporation, and fiber bonding develops as the paper contacts a series of steam-heated cylinders.
6. In the **calender** section the sheet is pressed between metal rolls to reduce thickness and smooth the surface.
7. The **reel** winds the dried, calendered paper onto itself.

These components form the basis of any Fourdrinier machine that is suitable for a wide range of grades. Many variations, modifications, and auxiliary on-machine operations have been developed for special grades and paper types, e.g., for surface sizing, surface coating, and special calendering treatments.

The Yankee dryer is another device used to dry paper, which at times is used as a part of a Fourdrinier machine. The Yankee dryer consists of a large diameter steam cylinder, which is mainly used for the drying. When a wet sheet needs to be dried, the sheet is pressed tightly against the polished surface of the Yankee dryer cylinder. The sheet is now transferred on the surface of the drum to avoid the generation of any tensile forces. The dryer is enclosed by an air hood and can be added with high-velocity impingement air to increase the drying of the sheet. The dried sheet is then scrapped off the drum surface using a Doctor blade.
Paper and Board Grades

The more common paper and board grades are:

1) Printing grades.
   a) Newsprint is an important family of non-coated printing papers. The functional requirements of newsprint are runnability on the printing press, printability, good general appearance, and low price. Newsprint furnish is a mixture of mechanical pulp and lightly refined chemical pulp.
   b) Catalog paper is lightweight newsprint that contains fillers.
   c) Rotogravure paper is uncoated newsprint that is more highly finished and may contain fillers.
   d) Publication paper is coated magazine paper. The raw stock typically consists of mostly ground-wood, but better quality grades include chemical pulp.
   e) Banknote and document paper is high grade and permanent paper. It is usually made from rag furnish.
   f) Bond and ledger paper is also high-grade paper made from rag or chemical furnish.
   g) Stationery paper is relatively soft and bulky with a good appearance. The highest quality paper uses rag furnish, but it is generally made from chemical pulp.

2) Industrial grades.
   a) Bag paper is of high strength, and is usually made from highly refined unbleached kraft pulp.
   b) Linerboard is a lightweight board that is commonly used as wrapping paper and as the outer plies of corrugated box stock. It is usually made from high-yield unbleached kraft with a better quality top liner for printing.
   c) Corrugating medium is used for the fluted inner plies of corrugated box stock. It is usually prepared from high-yield semi-chemical pulp.
d) Construction paper is a newsprint-type sheet of higher weight and bulk.

e) Greaseproof paper is a dense nonporous paper made from highly refined sulfite pulp.

f) Glassine is produced from greaseproof paper by dampening and applying heavy pressure. It is used for protective wrappings and is converted into waxed paper.

3) Tissues.

a) Sanitary tissues include facial and toilet tissues, sanitary napkins, and table napkins. The primary feature is softness and absorbency. These tissues contain a high percentage of lightly refined chemical pulp.

b) Condenser tissue is a lightweight well-formed tissue (weighing 5 g/m³) made from highly refined kraft. It is used as a capacitor dielectric, as a carbonizer, and, with wet treatment, for tea bags.

c) Toweling is a creped absorbent paper usually made from lightly refined kraft with the addition of mechanical pulp. The prime requisites for toweling are fast absorbency and water holding capacity. It is sometimes treated with wet-strength resins to prevent wet disintegration.

d) Wrapping tissue is a wide category of tissues made for wrapping and packaging merchandise. The general requirements are strength, good formation, and cleanliness.
CHAPTER III

Pulp and Paper Drying

The residual moisture in the pressed paper sheets is removed in the paper dryer. The dryer section is by far the most expensive part of the paper machine with respect to both capital and operating costs. For example, the production of over 60 million tons of paper in the US requires the removal of over 80 million tons of water. The machine speed, depending upon the type of paper grade, can vary between 500 fpm to 6000 fpm. The mainline width can vary between 30 ft to 200 ft.

About 7% of the industry water removal occurs in pulp drying, 6% in tissue drying, 34% in paper drying, 51% in paperboard drying, and 2% in coatings drying. About 80–85% of the industry drying is done on conventional drum dryers, approximately 5–10% on impingement dryers, and about 4–5% on Yankee dryers. Less than 3% of drying involves infrared dryers but there are significant opportunities to increase IR heater use for drying. Flash and vacuum dryers each account for about 1% of dryers and very little drying is done using dielectric and microwave dryers.

Description of drying process

In general, water is removed more cheaply by mechanical means than by using thermal energy, but it is hard to obtain a paper web with a moisture content less than 1.4 lb of water per lb of the fiber by mechanical pressing. Therefore, thermal drying is always required. In a thermal drying process, evaporation occurs most rapidly from the surfaces of fibers or from large capillaries. The dryer section where this type of evaporation occurs is called the constant rate zone.
Gas IR Application in Paper Drying Process

The diagram illustrates the relationship between the weight of water and the weight of fiber over time in dryers. The graph shows:

- **Sheet warm-up**
- **Constant Rate**
- **Falling Rate**
- **Bound**

The x-axis represents **Time in Dryers**, and the y-axis represents **lb. Water/lb. Fiber**.
When the sheet dryness reaches the point at which free moisture is concentrated in the smaller capillaries, the evaporation rate is reduced. This region is called the **falling rate zone**. Finally, at about 9% moisture, chemical bonds must be broken in order to evaporate more water in the bound-water zone. To illustrate this sequence, a typical drying curve is illustrated in figure 2. In general, the more the water evaporates in the constant rate zone, the higher will be the overall evaporation rate. This rate will be lowered if more time is spent in the bound-water zone. Most machines are forced to over evaporate in order to compensate for poor drying uniformity.

The typical drying rates are shown in figures 3 & 4 for linerboard and newsprint using conventional drying. In these figures, the variation of drying rates for linerboards and newsprint are plotted as a function of the steam temperature (pressure). It can be seen from these graphs that the steam pressures required to dry newsprint range from 10psig-40psig, whereas those required to dry linerboards range from 90psig-150psig.

Steam is used for conventional drying. The wet paper from the press section containing about 60% moisture is passed over a series of steam-heated rolls (usually of 5 or 6 feet diameter), where the moisture is evaporated and transported away by ventilation air. The wet web is held tightly against the rolls by a synthetic and permeable fabric called a dryer felt. Most paper machines have 3–5 independently felted sections, each with variable speed control to maintain sheet tension between sections and adjust for any sheet shrinkage that occurs.

Conventional paper drying occurs during two phases:
1. During the first phase, the sheet accepts sensible heat while in contact with the steam cylinder.
2. In the second phase, the sheet flashes off steam in the open draw between the top and bottom cylinders. This causes the sheet to cool spontaneously and become ready to again accept sensible heat.
Figure 3 TAPPI drying rate for linerboard
Figure 4 TAPPI drying rate for newsprint (machines over 2000 ft/min)
The major resistance to heat transfer is provided by the condensate layer inside the cylinder, the dirt film on the outer surface, and the air layer. The major resistance to steam flashing off in the pocket is the partial buildup of humidity, causing a lower pressure differential. Figure 5 presents the temperature profile through a dryer, thereby illustrating the various resistances to heat transfer which include:

1. The condensate layer thickness. This layer is the most significant resistance to heat transfer.
2. The condensate layer movement.
3. The accumulation of non-condensibles.
4. Rust and deposits, or the finish of the inside surface.
5. The thickness of the shell.
6. The outer surface dirt or corrosion products.
7. The air boundary between the sheet and the cylinder. The air layer is minimized by utilizing adequate felt tension to keep the paper web firmly against the cylinder surface.
8. The sheet roughness.
10. The surface structure of the sheet.
Figure 5 Temperature profile through a dryer illustrating the various resistances to heat transfer.
Heating Requirements

The heating requirements can be calculated from the water removal stipulations, and depend upon the given operating and paper web conditions. These requirements are independent of the type of heat source, although the design of the heat source inversely depends on the amount of heat that is required to properly dry the pulp and paper and the design configuration. When the paper web enters a heated space, water is removed both in the liquid phase and by evaporation. The temperature of the sheet during evaporation depends upon the vapor pressure in the web during drying that, in turn, depends upon the operating conditions, e.g., the pressure applied to the web in a nip zone. At low moisture contents, the heating requirements are larger, since the paper becomes more difficult to dry due to hygroscopic effects. However, this extra heating requirement is usually insignificant when compared to the latent heat required to evaporate the water, except when small changes in dryness at high dryness levels are considered. Based on these scenarios a basic energy balance can be readily developed for particular scenarios.

The normal heat source is latent heat of the steam as it condenses inside the dryer cylinders. Steam condenses at the saturation temperature defines by the system pressure, and is usually transported at temperatures above this, i.e., at superheated levels. As the steam pressure increases, so does the condensing temperature, and the latent heat decreases. Although the heat transfer rate increases with increasing steam pressure, more steam must be condensed for a given heat transfer rate. During the drying of multi-ply paperboard, it is important to maintain a progressive temperature increase through the initial dryer sections in order to avoid sticking and blistering, and sometimes to prevent heat sealing. Any evaporation differences between the top and bottom boards will affect the flatness of the finished board.

Pocket Ventilation

Permeable synthetic felts are used to provide ventilation. A schematic of permeable fabric providing displacement of air in a dryer pocket can be seen in figure 6. These felts carry air into
and out of the pocket. The air displacement is a function of felt permeability and machine speed. Additional hot, dry air is supplied to each pocket to supplement the heat transfer.

Improvements in drying rates and the moisture profile are realized with better pocket ventilation systems. Ventilation reduces the humidity or partial pressure of the air within the pocket. Since the driving force for vapor removal is the difference between the water vapor pressure in the sheet and its partial pressure in the surrounding air, proper ventilation increases the drying rate.

Figure 6 Illustration of a permeable fabric providing displacement of air in a dryer pocket.
CHAPTER IV

Gas Infrared heaters applications on a typical paper drying machine

In a conventional paper drying machine, the steam temperature and hence the drum temperature is directly related to the steam pressure carried in the drum. When the drums on a papermaking machine operate at their maximum rated pressures, increasing the steam pressure cannot raise the production rate. Furthermore, as a paper making machine ages and the drums corrodes, the steam pressure has to be lowered. Supplemental heating, which must be fitted to the existing papermaking machines, is often required to offset this loss in temperature and, consequently, productivity. The Pulp and Paper Industry is one of the largest single users of infrared heating in North America. The gas–fired infrared emitters are widely used in the paper industry as they provide a compact, high–intensity heat source that transfers its energy content without physical contact.

Infrared heaters are mainly employed for supplemental heating in three applications:

1. **Supplemental heating for drying of the paper web.** We can increase the efficiency of paper drying machine by 10% to 20% by using infrared heaters for supplemental heating along with the conventional steam drum dryers. The infrared heaters are used at various locations in a conventional paper machine as listed below,
   i. Tests have shown that installing infrared heaters ahead of the press section can increase machine productivity. The supplemental heat raises the water temperature in the web, thereby reducing its viscosity and improving the effectiveness of the pressing process. This process is called hot pressing, which have shown to increase the efficiency of the presses in removing water by 20%.
   ii. Infrared heaters are also used in-between the press section and the first steam dryer, where they constitute a preheating section. The purpose here is to raise the web temperature so that the first steam drums are free to begin the drying of the web instead of simply first raising the web water to its drying temperature. The IR burner
provides the sensible heating of the sheet prior to coming in contact with the first dryer, which is usually provided by the cylinders, hence improving the overall drying capacity. This preheating is also done to prevent the sticking of the product on the first dryer. This heating depends upon the product, water content, line speed, dryer temperature, etc.

iii. In some instances, the burners can also be located adjacent to the dryer, preferably at the bottom half of the dryer on the uphill side of the product flow. If this location is deemed unadvisable, then the burners can also be placed on the top of the dryer around 3” to 4” from its surface.

2. Drying coatings on the paper. Drying paper coatings is more cumbersome due to smaller amount of bulk moisture that must be removed. In this case, drying rates must be controlled carefully to avoid mottling and defects in the finished surface. A moving air source is often required to ensure that drying rates are not limited by the accumulation of water vapor above the web surface. Infrared heaters provide an attractive non-contact means of heating, since the solid surfaces of steam drums can damage the coating once they touch it. The infrared heaters are located after the coating section and before the coating dryer, to prevent the coating material from sticking to the dryer and also to expedite the drying process. A schematic of a paper coating drying machine with the locations for the infrared heaters is shown in figure 7.

3. It is very crucial to control moisture profiles across the width of the paper web to maintain product quality. Infrared heaters are used along with other control devices for temperature and hence moisture profiling across the web width.

It has been observed that when gas IR burners are used at the later stage of conventional cylinder drying, it can increase the drying rate and hence extend the constant drying rate period to the later stage of drying. IR heating is superior as more water can be removed in the constant rate evaporation zone as opposed to the falling rate evaporation zone. The sheet can reach the falling rate zone in the 10-12% web moisture range with IR heating as compared to the 30-35% web moisture range with the conductive process.
Figure 7: Drying powder coating.
When applying heaters in open spaces where the paper runs from drum to drum, care should be taken not to block operator access to the machine components. Figure 1 illustrates the possible infrared burner locations on a paper machine. Figure 8 contains an illustration of infrared heating that also uses a flotation air stream.

No matter at what stage in the paper drying do we install the gas IR burners, the exposure distance between the emitter and the web plays an important role in the drying process. A larger exposure distance between the emitter and the paper has a smaller view factor and hence a lower IR energy density leading to lower drying rate. At the same time if this distance is kept less than what’s deemed advisable, the IR radiation might be intense and might damage the web. Also if the emitter temperature is more than necessary, the web surface might dry faster, hence increasing the reflectivity of the surface resulting in the lowering of the IR absorption and the drying rate.

Since the infrared radiation unit only supplies the heat, air must be provided to carry away the moisture that is evaporated from the coating. The effectiveness of the burners is increased by scrubbing the vapors accumulated on web with hot flue gases. Some drying units, therefore, combine both infrared and air impingement dryers. This increases the potential for the water on the surface of the web to evaporate increasing the drying rate. The temperature and the velocity of the blowing air affects the drying rate. Higher the temperature of air and higher its velocity, the drying of moisture from the web surface is increased, within the requisite limits of operation. The blowing air if re-circulated, an increase in re-circulation increases the temperature of the air hence higher drying rate. This increase in the re-circulated air also increases the humidity of the air around the web surface, decreasing the potential to evaporate the moisture from its surface, but it was observed that the effect due to increase in the air temperature on the drying rate was more prominent.
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Figure 8: Illustration of infrared heating using a floatation air stream.

The comparison between various paper-drying systems can be seen in table 1.

Figure 9 Diagram of the gas-fired IR drying element. 

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**Table 1**

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<th>System Type</th>
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<td>Cornbust~on Exhaust</td>
<td>Web</td>
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<tr>
<td>Reflected IR radiation</td>
<td>Web</td>
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<td>Ventilation and cooling air</td>
<td>Web</td>
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The application of gas infrared heaters when used to dry paper web is shown in figure 9. It can be observed from the figure that incident infrared energy is either directly emitted from the emitter or is reflected by the emitter panels. The ventilation and cooling air as mentioned earlier is shown along with the evaporation of moisture from the web surface. The use of supplemental air for the removal of moisture from the surface of the web, along with the air blowers, is shown in figure 11.

![Graph showing absorption coefficient of water with respect to wavelength.](image)

Figure 10: Variation of the absorption coefficient of water with respect to wavelength.

When IR burners alone are used to dry paper, we come across the lack of the constant rate period for the drying process. This is due to the variation in the heat transfer to the web, as result of variation of absorption of the IR energy absorbed. This is because of the lower reflectivity of IR energy by wet materials, due to multiple internal reflections, as compared to that by the dry materials. Thus as the drying of the web continues, the reflectivity of the web increases until it becomes constant when the paper surface becomes dry. As result of this variation in the reflectivity of IR energy from the web surface, the heat transfer by IR burner decreases till the sheet surface dries up.
Figure 11: Supplemental air movement for gathering accumulated moisture.
Water is a selective absorber for the transmission of radiation. The absorption coefficient $a_\lambda$ determines the exponential attenuation of the radiation intensity. In the visible region (where the wavelength $\lambda$ is in the range 0.4–0.7 µm), the absorption coefficient is quite small in case of water. In the vicinity of a micron, i.e., 1 µm, $a_\lambda$ begins to increase, and at longer wavelengths in the infrared region the absorption become quite large [1]. The variation of the absorption coefficient of water with respect to wavelength is contained in. This behavior is significant in the case of pulp and paper drying, since moisture removal necessitates the absorption of thermal radiation by water. Therefore, the radiation should be supplied at longer wavelengths. In general, electric IR radiant energy is in the short-to-medium wavelength regions at which the radiation does not optimally match the absorption characteristics of water. In contrast, natural gas IR emitters provide energy at the longer wavelengths (2–6 µm) that match the absorption by water. Data for the variation of the absorption coefficient of water with respect to wavelength is presented in figure 10.

In case of thin paper webs, the absorption of the IR energy depends on their thickness and also on the wavelength of the incident IR energy.
Table 1: Drying performance of various systems.

<table>
<thead>
<tr>
<th></th>
<th>Air float</th>
<th>High velocity impingement dryer and cylinder</th>
<th>Infrared heating with low velocity air circulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal efficiency</td>
<td>4—50%</td>
<td>60—65%</td>
<td>60—65%</td>
</tr>
<tr>
<td>Heat transfer rate</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Energy usage</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Water evaporation rate</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Drying uniformity</td>
<td>Fair</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Different drying across web</td>
<td>Moderate</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Wet film internal heating (positive vapor pressure)</td>
<td>Poor</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Cross–web adjustment of drying intensity</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Moisture leveling and conditioning</td>
<td>Fair</td>
<td>Fair</td>
<td>Good</td>
</tr>
<tr>
<td>Curl control</td>
<td>Good</td>
<td>Fair</td>
<td>Good</td>
</tr>
<tr>
<td>Sticking</td>
<td>Good</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Maintenance and downtime</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Capital investment</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Operating cost</td>
<td>Fair</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Environmental heat transfer</td>
<td>Fair</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Noise level</td>
<td>Fair</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Space required</td>
<td>Fair</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>
Surface Treatments

The physiochemical processes that need to be done on the dried paper to improve its quality are described below.

Sizing
Surface sizing operations are primarily performed to provide the paper surface with a resistance to aqueous solutions. This treatment also provides better surface characteristics and improves the paper qualities. Internal sizing utilizes resins or other chemicals to reduce the water penetration rate by affecting the contact angle. Surface sizing typically uses starch particles to fill the surface voids in the sheet, reducing the pore radius and, therefore, the liquid penetration rate.

Coatings
Many paper surfaces are coated with suitable formulations that provide improved gloss, slickness, color, printing detail, and brilliance. A paper coating is typically a layer made up primarily of fine mineral pigment. Lighter coatings are applied on-machine, while heavier ones are usually applied off-machine. Coatings tend to fill the void areas on the paper sheet surface. Surface coatings cannot compensate for poor raw stock, and the base sheets are usually sized prior to the coating process.

Conventional steam methods are sometimes used to dry coatings but, more often, other methods are used to avoid disturbing the coating film. The most commonly employed methods are hot air impingement and infrared drying. Single-sided coatings are dried by placing high-velocity convective hoods over conventional steam dryers. Another method used to dry both single- and double-coated sheets is tunnel drying. In this case the paper is either carried round on rollers, supported on foil, or is held up by air impingement. The tunnel temperature is controlled to suit the drying requirements and the machine speed.
CHAPTER V

Gas and Electric IR Burners/Heaters

There are several types of gas and electric IR heaters. However, we have focused only on those heaters that are widely used in paper drying process.

Gas IR heaters

Natural gas IR heaters generally consist of a metal or ceramic emitter placed in a metal housing acting as a passage for gas/air mixture. Gaseous fuel and air are mixed in proportions to sustain combustion at or below the emitter surface, to provide 1600 °F to 2100 °F surface temperature. Specific types of burners are as described in Table 2 below.

Table 2: Characteristics of natural gas–fired infrared sources.

<table>
<thead>
<tr>
<th>Type of Burner</th>
<th>Performance</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Combustion Burner</td>
<td>Firing rate 25-125 kBTu/hr/ft²  Combined Efficiency 80 - 90%  Thermal Response - ceramic fiber 5-10 sec  - metal fiber 15-85 sec  Cooldown time 1 sec  Operating hours 10,000-15,000 hr  Temperatures 1300-1900°F  Turndown ratio 3/1</td>
<td>Acotech, Marsden, Glenro</td>
</tr>
<tr>
<td>Impingement Type</td>
<td>Firing rate 30-150 kBTu/hr/ft²  Combined Efficiency 65%  Thermal Response 30 sec  Cooldown time 900 sec  Operating hours 8,000-10,000 hr  Temperatures can reach 2100°F and above  Turndown ratio 10/1</td>
<td>Eclipse, Indesco, Pyronics, Red-Ray, Burdett, Advance Curing</td>
</tr>
<tr>
<td>Ported Tile w/without Screen</td>
<td>Firing rate 30-80 kBTu/hr/ft²  Combined Efficiency 65 – 70 %  Thermal Response 60 to 300 sec  Cooldown time 200 sec  Operating hours 8,000 hr  Temperatures 1600-1850°F</td>
<td>Maxon, Solaronics, Perfection Schwank, Eclipse</td>
</tr>
</tbody>
</table>
**Electric IR heaters**

Infrared radiation occurs at short, medium, and long wavelengths, and there is a multiplicity of electric IR emitters.

1. *Short wavelength emitters* normally operate in the 1650–2200°C (3000–4000°F) temperature range. Tungsten filament lamps can convert over 80% of electrical energy into thermal radiation energy, and reach steady operating temperatures in a fraction of a second. However, these operating data are significantly lower in temperature when an envelope is used with the emitter.

2. *Medium wavelength emitters*, such as quartz tubular heaters, contain a high temperature nichrome wire as the filament and usually operate in the temperature range from 980–1100°C (1796–2012°F). These emitters convert about 50–60% of the electrical energy into thermal radiation.

3. *Long wavelength emitters*, such as radiant panels, normally operate in the 540–650°C (1000–1200°F) temperature range, and convert 50–65% into IR radiation at normal operating conditions.

Gas infrared technology is exclusively used for drying. It is perceived that electric IR systems are more flexible and can be used:

1. Strictly for coating drying (usually immediately following the coater head to quickly set the coating).
2. For base-sheet moisture profiling prior to the coating.
3. For moisture profiling prior to the reel.
The flexibility of electric IR systems arises from the modulated control ability that is inherent to electricity. Electric IR systems can be readily segmented into a series of heating zones with 0–100% power control over each zone, making them ideal for moisture profile control. Due to the nature of combustion, gas IR systems must always operate at a minimum firing level, reducing their range for moisture control. The determining factor between the two systems is the electricity cost, gas IR systems are advantageous from a cost perspective if the electricity cost rises, the maintenance costs can be higher for electric emitters. The life of electric IR emitters (3000–5000 hr) is short as compared to gas IR sources and the convection component in a gas application assists the radiation heat transfer during the drying process.
Gas IR Application in Paper Drying Process

CHAPTER VI

Alternate Heating Technology

Gas heated dryers have been developed. These dryers consist of a cylindrical dryer that is heated by an infrared burner. Combustion occurs inside the completely enclosed dryer. Very high cylinder temperatures are possible, since it is not a pressure vessel. In practice, face temperatures of 300°C can be reached, resulting in drying rates that are up to three times higher than conventional steam cans for grades such as linerboard. Drying rates up to 5 times as high as those of steam cans have been measured for lighter paper grades such as tissue, towel, and other fine paper grades.

In general, gas heated paper dryers have achieved drying rates in excess of conventional steam cylinders, since the gas heated dryers operate at higher temperatures. Gas heated dryers are not pressure vessels and, consequently, are not problematic from that perspective. Machine downtime in case of gas dryers is lower, since they can be installed in as little as two days. The machine configuration can remain unchanged if gas heating is used, it is user and environmentally friendly, and production capacity increases are achieved with incremental reductions in total operating costs. The comparison between the various paper-drying methods is described in table 3.
### Table 3: Various methods used for paper drying

<table>
<thead>
<tr>
<th>Drying type</th>
<th>Heat &amp; mass transfer</th>
<th>Drying rate</th>
<th>Advantages</th>
<th>Limitations</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-cylinder (conventional)</td>
<td>Conduction heating. Mass transfer by diffusion.</td>
<td>10–20 kg/m²-hr</td>
<td>Used for a long time, therefore, familiar. Temperature of each cylinder can be separately adjusted for various paper grades.</td>
<td>Lower drying rate. High heat capacity so that control is difficult and the moisture content in the paper is nonuniform. Equipment is very large.</td>
<td>Difficult to improve further.</td>
</tr>
<tr>
<td>Impingement drying</td>
<td>Convection heat and mass transfer. Some radiant heating</td>
<td>100 kg/m²-hr (for $V_{air} = 100$ m/s; $T_{air} = 315°C$)</td>
<td>High drying rate. Suitable for drying coatings and pulp sheets. Fast response due to negligible thermal inertia.</td>
<td>May not give the sheet a smooth surface. High power consumption.</td>
<td>Extensively used in drying coatings, photographic film, pulp sheets, etc.</td>
</tr>
<tr>
<td>Yankee dryer combined with impingement drying</td>
<td>Heating by conduction, convection, and radiation. Mass transfer by convection.</td>
<td>200 kg/m²-hr (for $V_{air} = 100$ m/s; $T_{air} = 315°C$; $P_{steam} = 8$ kg/cm²). About half of the heat in the air is transferred to the web.</td>
<td>Highest drying rate of all dryers. No sheets are broken. High speed operation. Very large units in operation (up to 5 m diameter).</td>
<td>Only suited for tissue drying.</td>
<td></td>
</tr>
<tr>
<td>Press Drying</td>
<td>Heating by conduction, mass transfer by diffusion.</td>
<td>80 kg/m²-hr (for $T = 10°C$). 120 (for $T = 180°C$).</td>
<td>Increased paper strength. Smooth paper surface. Poorer furnish can be used.</td>
<td>Cannot be operated at high speed. Requires strong, porous, but nonsticking fabric. Web can stick to the cylinder.</td>
<td>Under development.</td>
</tr>
<tr>
<td>Convac drying</td>
<td>Conduction heating, convection mass transfer.</td>
<td>150–200 kg/m²-hr</td>
<td>Shorter drying section length. Smooth sheet surface.</td>
<td>Higher power consumption. Higher steam pressures. Web can stick to the cylinder.</td>
<td>More development required.</td>
</tr>
</tbody>
</table>
CHAPTER VII

Major manufacturers and their burners applications

In the following section, several case studies are presented for different gas IR heater applications. Details of the content and product specifications can be obtained from respective manufacturers.

**Marsden:**
1675 Hylton Road,
Pennsauken, New Jersey 08110-1313
Ph: (609) 663-2227, Fax: (609) 663-2137
URL: [http://www.marsdeninc.com](http://www.marsdeninc.com)

They manufacture custom designed gas infrared systems for the pulp and paper industry. Their IR systems provide the fastest heat-up and cool-down rate among all other gas IR burners. Due to their unique ceramic fiber pad and multi-layer construction, burner operates safely, avoiding any safety concerns.

These systems are designed for use in,
- Preheating
- Incremental Drying
- Coating Drying
- Moisture Profiling

Some of the features of their gas infrared systems are as follows,
- Five second emitter heat-up.
- One second emitter cool-down.
- Specially designed to prevent flashback.
Gas IR Application in Paper Drying Process

- Average moisture evaporation rates of 20+ lbs/sqft.hr as compared to 5 lb./sqft.hr by steam cylinders.
- Radiant efficiency is 50% to 65% while the highest emittance is 0.96, all this while providing 100% radiant surface area per unit area.

Marsden studied the application of their IR heaters to dry a very heavy paperboard travelling at 220fpm with 92 cylinder dryers. The IR heaters were used to heat the sheet before the first dryer, and found that this provided the sensible heat to the sheet rather than the usual source of the first few drying cylinders. This allowed to increase the pressure in the initial cylinders and helped improve the overall drying capacity in addition to the increase in drying from the IR dryers.

If the IR heating needs to be applied at the dry end of the paper machine, it should be noted that the IR burners should not put too much energy into the sheet as it causes the steam cylinders to cool the sheet instead of heating it. This might save the amount of steam used here but we will be wasting IR energy applied. Thus we need to find an optimum combination of using both these types of energy sources.

**Krieger:**
360 Narrangansett Park Drive,
East Providence,
Rhode Island 02916
Ph: (401) 438-0570, Fax: (401) 438-8196

They are one of the major supplier to the paper industry on a world wide basis. Their product line consists of,
- Infrared dryers
- Air flotation dryers
- Contact free sheet control devices
Gas infrared dryers are used for this application due to their compactness, provide homogeneous warm-up and water evaporation. They use a metal infrared emitter with nozzle mix and a combustion efficiency of 54%. Krieger’s K6500 gas fired metal emitter provides homogeneous heat-up and drying of coating as the wavelength of the emitted IR radiation matches the absorption spectrum of water. At approx. 1920 °F, most of the IR energy is emitted in the wavelength range of 2μm to 6μm and thus ideal to heat up water. Krieger’s IR burners are placed 6 inches from the sheet to avoid any overheating of the sheet and also to allow the removal of the exhaust gases from the IR dryers.

The coating applied on both sides of the sheet at solids contents of 30-65%, which needs to be dried. To prevent the picking on the process equipment, the solids content of the paper and coated surface is to be higher than 72% to 76%, or if the overall sheet moisture is less than 15%. Metering size presses improve the surface quality of the paper being produced, and so coating drying process contributes to improved quality.

Non-contact drying is done to prevent the picking of coating or size particles on the drying cylinders, felts, paper rolls, and spreader rolls. CB-Turn and stabilization nozzle provides a wrinkle and flutter-free sheet control of wet paper by providing an air cushion for carrying the wet paper. The Infra-Float system consists of a combination of infrared dryer with a hot air dryer and a joint air circulation system achieving an efficiency of 75%.

During the drying, the saturated air from the web surface is removed to increase evaporation rate. During evaporation, coating, water and dissolved components like binder migrate towards the surface. After the water has evaporated, the rest of the components migrate back non-uniformly into the paper, thus forming uneven binder distribution and hence non-uniform ink absorption causing mottling. This can be avoided by preventing the overheating of the coated surface during heat up and drying. The IR heaters avoid the overheating by uniformly heating the paper mass and by removing the moisture laden air and the exhaust air away from the paper surface.

Krieger uses a water/steam mix, which creates a fog in front of the IR heater and squelches any fire. Hence in the event of a sheet break, the air circulation system switches into "High speed
100% blowing” mode, blowing the sheet away from the emitter faces and also sprays a cool mix of steam and water at a pressure of up to 3.5bars (50psi) into the dryer area.

When the web comes into contact with the dryers during the cool-down, there is a chance that the evaporation might stop and that the boundary layer of saturated air will condense again. The integrated air section is to accelerate the removal of this saturated layer before coming in contact with the drying cylinders. The heating needs of this section are provided by the exhaust from the IR system resulting in an overall efficiency of more than 60% depending upon the ratio between IR and air section length.

Krieger does not recommend profile drying over cylinders or at the dry end due to the following,

- Profile correction in dry areas cause bad sheet temperature profiles, which may transform into calendar and reel building related problems.
- It is easier and more cost effective to remove water in the constant rate zone.
- Profile control systems over cylinders reduce the drying capability as a large amount of energy is absorbed by the cylinder.

Solaronics:
2161 Newmarket Pkwy.,
Suite 220,
Atlanta, Georgia 30067
Ph: (770) 951-5667, Fax: (770) 951-8051

Solaronics offers high intensity gas IR burners having ported tiles with metallic and ceramic screens. Due to intense combustion close to the surface and within a specially designed ports their efficiency can vary between 35%-55%. Following are some examples where their burners have been used to improve the overall efficiency. Some representative results obtained from industry are now discussed. Detailed results for a specific case are presented in Ref. ii.

1. The objective in one application was to speed up a paper machine (used for a coat drying application) by 22%. Natural gas–fired infrared heaters were installed in a hood after each of
the two coating stations. Each of the two hoods consisted of three rows, with each row containing 27 emitters. The total installed power was 1130 kW (3,870,000 BTU). Preliminary results indicated a speed up of 24%, quality improvements of 30%, 100% fire safety, and energy savings of 10–15%.

2. A second application involved a pulp dryer used to boost the drying capacity of bleached sulfite hard and soft pulp. The objective was to speed up the process by 5%. A natural gas–fired IR system was installed in a two-hood configuration. Each hood consisted of three rows, with each row containing 32 emitters. The 5% speed up was accomplished with not IR color influence. The system also allowed for a 30 psi pressure drop in the Flakt dryer.

Impact Systems:
14600 Winchester Blvd.,
Los Gatos, CA 95030
Ph: (408) 379-0910, Fax: (408) 379-7275
URL: http://www.impactsys.com

The Spectrum-IRTM lle Gas Infrared Drying System is designed for all types of incremental drying and coating applications. Some of the features of this system are, concise foot print, rapid heat-up and cool-down, high efficiency and drying capacity. DuraGlow, a high-intensity gas infrared emitter, is durable, corrosion proof and has a low thermal mass, and a high thermal resistance burner surface. Its frame is made up of stainless steel that houses the DuraGlow emitter modules with dimensions of either 6”x8” or 6”x12”. The combustion takes on the outer surface of the fibrous emitter and extends no more than ¼” from it, maximizing emissivity and radiant coupled energy.

Their Gas Infrared Drying System provides virtually instantaneous cool down eliminating fire hazard associated with conventional gas systems. Has highest energy density combined with multiple emitter sizes providing drying capacities with minimum space and installation
requirements. The gas IR dryers can be used with line basis weight sensor, to provide superior spatial resolution for streak detection, edge of sheet measurement, and tight CD profile control.

**Eclipse Combustion:**

1665 Elmwood Road,
Rockford, Illinois 61103
Ph: (815) 877-3031
www.eclipsenet.com

Eclipse #67 IR are the impingement type of burners manufactured by Eclipse Combustion. These burners have high energy intensity and a concentrated radiation. The Fourdrinier forming section of a papermaking machine, with no pressing section, could not meet the machine speed requirements. Thus eight rows of 156” Eclipse #67 IR burners were installed above the dryers, with a few of them mounted upstream of the first dryer. The IR burners above the dryers increased the production by 18% while the other units increased the line speeds to the desired levels. Similar units were later installed in this industry for hot pressing, binder migration control, setting of size and coatings, drying of coatings, etc.

Another paper coating operation had insufficient drying, lack of burner control and high maintenance of Kraft Board. The infrared units originally present could not meet the temperature requirements to set the binders and also had no modulation control. Three rows of Eclipse #64 IR burners with direct spark ignition were installed. This increased the quality of the coating due to proper burner control, increased production with higher throughput and hardly any maintenance. Thus a similar unit was installed in the second zone of this coating operation and also for off-machine coaters, hot pressing, on-machine drying, profile control, and curl control.

In summary, different gas IR heaters, depending upon their firing capacities, result in different thermal performance i.e. heat flux, surface temperature and spectral energy distribution. Therefore, their performance vary in paper or coating drying. Their orientation towards the paper
sheet may vary as well to maximize their effectiveness. It is crucial to maintain the optimum distance between burner surface and paper sheet to achieve the operational benefits of infrared heaters. Of course, this is highly dependent upon the paper grade and their respective locations.

New gas IR heaters have many of the same features as electric IR systems. Heater surfaces are now able to reach the steady state temperature within seconds, making their cool-down and heat-up rates almost comparable to those in electric systems. Consequently, newer gas IR systems can be placed closer to the sheet surface, thereby allowing more energy to be applied to the web with a resultant increase in the drying rate. Newer gas IR emitters have longer emitter lifetimes as compared to older technology. Due to these developments, differences in gas and electric IR drying rate efficiencies have all but disappeared. However, the two technologies are not interchangeable. The determining factors while choosing between the two systems are

1. The objective of the application, and
2. The cost and availability of the energy.
Controls/Safety

The common perception about IR burners is that due to their high heat flux, there is a greater chance of fire hazard in a paper-making machine. One way to address this problem is to use the IR burner at the wet end of the paper machine rather than at the dry end. In case the web is broken here on the wet end and fed directly into the burners, the web by itself will not allow combustion. This is due to the high moisture content of the web and so the web might char but not burn.

Other developments to ensure safety and reliability of gas IR heaters has led to the development of quick-cool burner emitters that have a low thermal mass and, consequently, cool rapidly after they are shut off. A sheet break detector triggers the shutoff of natural gas to the burners while combustion air continues to flow to convectively accelerate the cooling process.

To prevent the web from overheating and also to allow the scrubbing of hot flue products from its surface, IR heaters must be located 2.5"-6.0" from the web surface. Although devices such as photo cells, speed switches, etc., are used to shut off the gas valves, precautions should be taken to avoid the risk of a fire hazard.

In the event of a fire hazard in the paper machine, Krieger uses a water/steam mix which creates a fog in front of the IR heater and squelches the fire. In case the sheet breaks, the air circulation system switches into “High speed 100% blowing” mode blowing the sheet away from the emitter faces and also sprays a cool mix of steam and water at a pressure of up to 3.5bars (50psi) into the dryer area.
### Conversion Table

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Metric/English</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>1 m (=100 cm) = 39.37 in</td>
</tr>
<tr>
<td>Area</td>
<td>1 m² (= 10⁴ cm²) = 1550 in² = 10.764 ft²</td>
</tr>
<tr>
<td>Volume</td>
<td>1 m³ (= 10⁶ cm³) = 35.315 ft³</td>
</tr>
<tr>
<td>Energy, Heat</td>
<td>1 kJ (=10³ J) = 0.94782 Btu</td>
</tr>
<tr>
<td>Heat Flux</td>
<td>1 W m⁻² = 0.3171 Btu/ hr-ft²</td>
</tr>
<tr>
<td>Mass</td>
<td>1 kg = 2.2046226 lbm</td>
</tr>
<tr>
<td>Temperature</td>
<td>T(°F) = 1.8 (T(°C) + 32)</td>
</tr>
<tr>
<td></td>
<td>ΔT(°F) = 1.8 ΔT(K)</td>
</tr>
</tbody>
</table>
References


