FIRES IN MICROWAVE AND RF HEATING SYSTEMS: CAUSES AND PREVENTION

Robert F. Schiffmann
R.F. Schiffmann Associates, Inc.
149 West 88th Street
New York, NY 10024-2401

ABSTRACT

Fires in microwave and RF heating systems are not uncommon. However, they are often avoidable or controllable once ignited. Fires may occur due to overheating of the product, the conveyor or other structural elements in the applicator. Arcing is another common cause of fires, and this may be due to tramp metal or charred particles on the conveyor, for example. There are design elements that can be incorporated to prevent fires, such as fire and arc detectors, and conveyor belt cleaning systems. However, should a fire start it is important that systems and plans be in place to contact the fire department, contain or put out the fire and minimize damage and other hazards. The paper discusses various causes of fires, how to prevent them and how to control them if they start.

INTRODUCTION

Fires are not uncommon in consumer microwave ovens. They are most commonly caused by such things as severely overheated food or packaging, arcing of metal pieces or foil bags; and heating of improper non-food products such as cotton clothing. What is less known is the occurrence of fires in industrial microwave and RF processing systems. For example, this author is aware of four such fires, which occurred within the last five years. Their effects ranged from total destruction of the processing equipment to burning down the building in which the equipment was housed, as well as destroying the equipment. The causes for these fires varied and included flaws in the equipment, and inadequate fire suppression systems. All of these things are examined in the following.

WHAT IS A FIRE?

From a chemical as well as a physical point of view, a fire is a catastrophic event. There are three essential elements for a fire to occur: fuel, oxygen and a source of ignition. A fuel is any substance that will release energy when it reacts with the oxygen in the air, given a start by an external heat source or an igniter. Typical fuels are wood, paper, oils and fats, plastics, kerosene and gasoline.

The chemistry of fires is very complex , and even simple 2 and 3 carbon chain hydrocarbon fires involve over 100 chemical reactions. The experts do not at all attempt to theorize the chemistry and physics of complex materials such as paper and wood. However, there are some things that are known about fires in general. They result from the temperature of the material reaching the ignition temperature, which effectively raises the energy state of the material to exceed the activation energy required for a chain reaction to begin. The chemical reactions that follow, are all exothermic, and consequently the temperature of the flame rises very rapidly as the energy of one reaction exceeds the activation energy required to initiate the next reaction. Thus, for example, the ignition temperature might only be 300° C, but the actual flame temperature might exceed 3000° C. In this chain reaction, there are usually several different basic types of reactions, the first being chain initiating steps which are elementary reactions, where one or two normally stable molecules result in the development of one or two chain centers. A chain center, in turn, is represented by atoms and free radicals, which participate in reactions in small amounts that create large changes. Another important set of reactions which occur in flame chemistry, are chain branching reactions, that is, reactions in which the number of chain centers will increase from one or two to three or more. Examples of these reactions would be on the order of the following:

(a) Chain initiating step C_3H_8 ? $C_2H_5 + CH_3$.
(b) Chain center formation $CO + OH^-$? $CO_2 + H^+$. Here the OH^- radical is a reactive intermediate which yields another reactive intermediate the H^+ radical, which in turn, may again react to yield the OH^- radical.
(c) Chain branching reaction $H^+ + O_2$? $OH^- + O^-$. This is probably the most important of the chain branching reactions occurring in hydrocarbons.
(d) Chain terminating reactions $H^+ + OH^- + N2$? H2O + N2 (stable).

In order to initiate a fire, the important thing is to raise the temperature of the fuel source to its minimum ignition temperature. This can be done through several ways in a microwave or RF environment. One is to expose it to a very high temperature, as one might see in an arc. Here, not only is the temperature high, but the arc also contains free electrons and oxygen atoms which can enter into the chain reaction. Another cause of fire would be for the process material or the conveyor belt to ignite. These and other causes are decribed in detail, below

MICROWAVE AND RF ENERGY AND FIRES

It is important that manufacturers and users of microwave and RF processing equipment understand the causes of fires and means to prevent them if for no other reason than that the presence of electromagnetic energy can cause the fire to burn more vigorously. Flames are plasmas and are rich in free radicals. It has been shown that microwave and radio frequency energy can couple into hydrocarbon flame plasmas because of the high electron density that exists in the flame front as a result of chemical ionization. The result is the acceleration of chemical reactions due to the energized flame-front electrons (1). In other words the fire can burn hotter and more vigorously, which can increase its destructive effects.

WHERE CAN MICROWAVE AND RF FIRES OCCUR?

Fires may occur in both batch ovens and conveyorized systems. In both cases there is a plentiful supply of oxygen (fresh air) from such things as magnetron cooling fans and open-ended conveyor tunnels which actively draw in large volumes of air due to the use of exhaust fans on the cavity.

CLASSIFYING THE SEVERITY OF MICROWAVE AND RF FIRES

Mild

These fires are confined to the applicator and do minimal damage. There may be smoke; scorching, mild melting or pitting of the conveyor belt; damage to the material being processed; etc. However, the electronics are not affected, there is minimum maintenance, and the system may be operated soon after the fire.

Serious

Again the fire is confined to the applicator or cavity. However, there is severe damage to the interior and exterior of the system. Components, such as the conveyor belt, belt support system, door chokes, and observation windows, may need to be repaired or replaced. The material being processed may also be damaged to the point of being unusable. Considerable maintenance will be required and downtime may be several hours or even days.

Severe

Very severe fires cause all of the above plus damage to components external to the applicator. These include, but are not limited to, the generators, and auxiliary equipment such as the material feed system, exhaust systems, and take-away conveyors. Other components contained in the cavity may also be so severely damaged that they require replacement. Downtime may be considerable since the damaged equipment may need to be replaced if it cannot be repaired.

Very Severe

These are the fires that not only destroy the processing system but also seriously damage or destroy the physical plant in which the equipment is housed. It may also cause injury or worse to the plant personnel. In order to resume production, an entire new process line must be installed in a new building. Weeks or months are likely to go by before production can resume. This also results in the cost of replacing the equipment and plant, and lost income from not being able to produce the product.

CAUSES OF FIRES IN MICROWAVE AND RF SYSTEMS

The causes of fires can be broken down into three broad categories: the product; the system; and miscellaneous causes.

The Product

A number of factors involving the product may cause fires.

Overheating: the product may be overheated to its ignition point. There are numerous ways in which this may occur:

- Excessive microwave or RF power which may be due to:
  - Improper setting of the generator(s) so that excessive microwave or RF power is produced.
  - Applicator loading is too light, which results in an excessive amount of energy being deposited in the product, heating it too rapidly and to an excessive temperature.
  - Product has lower moisture content, or higher input temperature than usual. Unless the power is reduced this will cause more temperature rise than normal.
- Excessive time in the applicator, which results in the product temperature becoming too high.
  - Process speed is too slow: The process material should be continuously monitored to ensure that the proper processing parameters are maintained.
  - Continuous system "stops"; this is a common phenomenon in processing plants. It could be due to a breakdown or stoppage of the processing line before or after the microwave/RF system. The process material then sits in the applicator and will continue to heat if the power is kept on.
- Thermal runaway: this can be a serious problem for which there is little control except shutting down the power. Its possible causes include:
  - Low moisture containing process material
  - High salt content or ionic conductivity of the process material.
  - Increasing loss factor (e") with temperature. This is frequently seen with the drying of wood, paper, leather and cellulosic materials. An additional danger is that the autoignition temperature may be reached internally in the material, which can suddenly burst into flames as it is bought out of the applicator, even while standing on the factory floor.

- Arcing: Arcs are sources of very high temperatures, are rich in free radicals and, if an ignitable fuel is present, can cause fires from mild to very severe. Common sources of arcs are:
  - Excessive dehydration of products to a near bone-dryness, which leads to charring and carbonization.
  - High electric fields caused by edge-heating effects
  - Product being caught in or on a conveyor belt, which carbonizes as it keeps recycling through the active applicator. This is a common problem with pieces of meat and spices in microwave bacon cookers.
  - Contamination with metal, carbon or other arc producing materials.

The Processing System: The components of the processing equipment may be the cause of the fire. Several major categories can be described:

- Improper materials or components used:
  - Conveyor belt and/or superstructure not able to sustain high temperatures over long-time use. Polypropylene is used in many processing conveyors. Yet its dielectric properties change over time making it susceptible to ignition.
  - Conveyor or other structures exhibit thermal runaway. This can be due to an improper conveyor component being used, such as Nylon. Or, the conveyor may be in contact with a processing material having a temperature close to the belt's melting point where there may be a dramatic increase in loss factor, leading to thermal runaway. An example is bacon being cooked on a polypropylene conveyor belt.
- Improper equipment design, which may result in:
  - Localized hot spots in the material being processed.
  - Excessive microwave power, locally or over a broad volume of the applicator.
  - Power not well matched to the load, resulting in excessive "free' power, which leads to excessive heating.
- Improper fire suppression system. The choice of components to detect and suppress a fire once it is started is critical. Possible problems are:
  - Inadequate fire detection: fire detectors should be placed so they can "see" arcing and/or flame. If they are blocked in any way, they may be blind to certain processing zones. The choice of detectors is also critical. For example, an infrared detector can detect a flame, but cannot see through smoke, and so may be blinded while the product is smoldering. An ultra-violet detector would be far more useful since it can see through the smoke. Several independently located and controlled smoke detectors should also be considered.

  - Improper choice of fire suppressants: The common fire suppressants have specific use conditions. For example, Halon should be used in batch applicators and is of little use in open-ended conveyors. It is also useful for active flames, not smoldering. CO_2 would be preferred in these instances. Water is useful in many conditions, but for fires involving immiscible liquids, such as oil, it should be avoided.
  - Lack of a proper warning system: There should be audible and visual alarms alerting personnel to the danger so they may take steps to put out the fire and for the sake of safety.
  - Microwave or RF power continues in the presence of a fire. This can result in a much more serious and more difficult to control fire. It may also causes an otherwise mild fire to become very serious or catastrophic. The instant a fire is detected the microwave or RF power generators should be shut down and the fire suppression system activated. This can be done manually, but is best done automatically.
  - Microwave or RF power improperly ramped up following fire detection or suppression. Once the power has been shut down it should be slowly brought up to full power, in stages, checking all the while that the fire has not restarted. Otherwise, if a small source of flame still exists, it may cause it to erupt.
- Miscellaneous causes: These factors do not properly fit the other categories but are possible causes of fire:
  - Tramp metals: a pen, screwdriver or similar, negligently dropped on a conveyor belt can causing arcing.
  - Operating at full power with an empty oven. This may cause arcing or melt components and bring them to their ignition temperatures.
  - Improperly controlling power, i.e. providing too much power for too little or too dry process material.
  - Static electricity, which can cause arcing and ignition.

METHODS OF PREVENTING AND CONTROLLING MICROWAVE AND RF FIRES

Preventing Fires

It is always best to prevent a fire from occurring. The various methods of doing this include:

Product: various steps should be taken to avoid product problems

- Use metal detectors in the zone leading into the applicator to detect and eliminate any metal particles in the product.
- Inspect product to detect and eliminate any contamination. This can be be done visually or automatically.

- Minimize the possibility of charring. Mix the product thoroughly prior to conveying. Continuously monitor the moisture content of incoming material and avoid excessively dry material. Maintain the temperature of incoming material within narrow limits.
- Eliminate salt concentrations: Mix the material thoroughly; distribute spice blends uniformly.
- Avoid flammable liquids.

Equipment: numerous things may be done to reduce possibility for fires:

- Continuously clean and inspect the belt; remove debris; remove and replace charred sections of the belt. Use a belt scraper and washer when possible.
- Establish a regular cleaning and maintenance program to keep equipment in the best operating condition. Remove debris that may have accumulated in the applicator.
- Keep the interior walls of the applicator, wave guide windows, etc. clean and free of debris. High fat or oily materials produce aerosols of oil vapors, which condense on the applicator walls. Over time this may polymerize and become highly flammable.
- Install metal detectors to prevent any metal from entering the applicator. This prevents a major source of arcing.
- Avoid flammable or explosive atmospheres. Provide good ventilation. Use inert gas atmospheres if necessary.
- Remove sources of arcing, such as rough or sharp metal edges.
- Prevent sudden increases in microwave or RF power.
- Control the air input: Oxygen is a requirement for a fire. A small flame can result in a big fire if the airflow continues uninterruptedly. By stopping the incoming air and shutting the exhaust dampers, it is possible to choke a fire as soon as it starts.

Detecting Fire

If a fire occurs, it is important to detect it immediately, accurately localize it and determine its extent. These detection devices should be hard wired to control and operate the fire suppression systems as well as warning the plant personnel. They can even be directly linked to the local firehouse. Means of doing this include:

- Fire eyes in the applicator: there are essentially two types of fire eyes:
    - Flame detectors: these can be infrared or ultraviolet (see above). They must be located to see the entire applicator interior. This means there

usually should be at least two detectors in each applicator. They should be cleaned and checked for proper operation daily.
  - Opacity detectors: these will detect the presence of smoke, which can either precede or accompany a fire. They should be cleaned and checked daily.
- Heat sensors: these are usually placed in the exhaust stack and detect fires by a significant rise in the exhaust temperature.
- Smoke detectors: mentioned earlier, they may be located not only in the applicator but also in the exhaust stacks and the processing room. Since they are constantly exposed to fumes, they should be cleaned and checked periodically
- Alarms: It is important that these be both audible (sirens or bells) and visual (flashing light). These will alert personnel to the problem so they can take preventative and safety steps.

WHAT TO DO IF A FIRE OCCURS

If a fire occurs, immediate steps should be taken to extinguish it, control its spread and limit injury and damage

- Shut down microwave generators
  - If re-started, power should be ramped up slowly
- Shut down air flow into processing system
- Close dampers on exhaust
- Empty the conveyor, quickly but with care since the processing material and/or the conveyor belt may be burning.
- Energize fire extinguishers
  - Inside equipment and room
- Energize alarm systems
- Get all personnel out of building <u>fast</u>
- Call fire department

REFERENCES

[1]M.A.V. Ward. “Potential Uses of Microwaves to Increase Internal Combustion Engine Efficiency and Reduce Exhaust Pollutants,” *Journal of Microwave Power*, **12** (3) 187-197 (1975).