Analysis of the air conditioning systems in a blown films manufacturing plant in the southeastern United States

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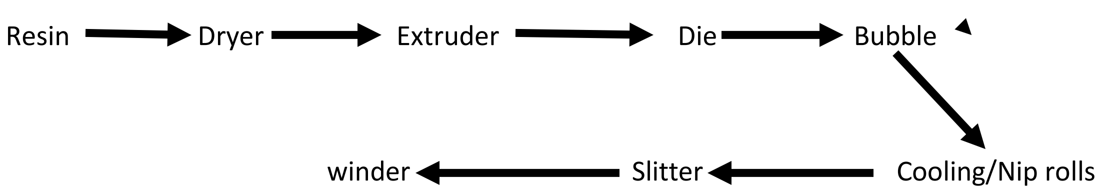
ABSTRACT – This paper is a study of the ventilating and air conditioning systems in a blown films manufacturing plant with a substantial number of heat producing plastic extrusion machines and significant building envelope cooling requirements. Many manufacturing technology educational programs include a course in polymers or plastic product manufacturing. Plastic extrusion, injection molding and film production processes require special considerations to accurately calculate plant cooling requirements. This paper provides a brief discussion describing a step by step design process. Included in the analysis are the cooling loads created by the employees, lighting and miscellaneous equipment. A brief discussion of a typical blown films manufacturing line provides the background information for cooling load calculations. Heating, cooling and ventilation equipment is expensive to purchase and to operate, but process stability and employee satisfaction are two major benefits to be realized.

Keywords: blown films, cooling load, ventilation load, energy conversion

INTRODUCTION

Nearly everyone in the United States uses blown film produced plastic products. Shopping bags, food packaging and construction films are among the family of plastic film products often made on blown-film lines. A typical line includes resin handling equipment, one or more extruders, cooling rolls, nip rolls, slitters and winding rolls.

Blown Film Process, Figure 1, Source: Authors



Typical plastic resins used in blown films include polypropylene (PP), linear low density polyethylene (LLDPE), low density polyethylene (LDPE) and high density polyethylene (HDPE and many others [1]. Resin systems may include only a blower, resin piping lines and a resin box on smaller, one extruder systems. Larger, higher

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throughput systems might include railcar supplied resin silos with elaborate, computer controlled resin lines and gates, multiple blowers, heated resin dryers and hoppers. Resin enters the extruder(s) as a solid pellet.

Extruders come in various sizes and output capabilities. One manufacturer described extruder sizes between 2.5 inches and 6 inches and motor horsepower between 40 and 400 [2]. A blown film line may include only one extruder, but as many as 11 extruders have been used to co-extrude a film which has multiple properties as needed based upon customer requirements. Barrier, stiffness, flatness, tensile strength and porosity are but a few of the film properties which may be manipulated [4]. The extruder will melt the resin to the proper temperature to allow it to flow into the mold, leaving as a film of desired thickness. As the film leaves the mold, air is injected into the film tube created, hence the name blown film.

The blown film is cooled, typically on chilled water supplied rolls, nipped and slit to create a single ply, specific width plastic film which may include multiple layers when co-extruded by multiple extruders. This film is then wound upon finished rolls for shipment to the customer. The description of a blown film line provided here is an elementary one. Blown film line configurations may be different based upon the manufactures specifications. This description is provided only to demonstrate the complexities of producing a plastic film. Proper manufacturing space temperature control will assist a blown film process engineer to better produce a consistent quality product in addition to enhancing employee workplace satisfaction.

The discussion which follows will discuss how to determine the quantity of plant cooling required for a blown film manufacturing operation in the southeastern United States (US). The southeastern US has four annual seasons requiring that heating and cooling loads be considered. A typical ventilation load calculation will consider the connected horsepower of the production machinery, the type construction of the building envelope, the number of employees in the manufacturing area, lighting and any other heat producing operation in the same space. Many manufacturing technology educational programs include a course in polymers or plastics manufacturing. Plastic extrusion, injection molding and film production processes require special considerations to accurately calculate plant cooling requirements.

DISCUSSION

There is much information which must be collected to accurately determine the cooling and heating load of a manufacture area. Often, for blown films lines, the electrical load and resulting heat generated is a major heat load. The next thing to consider is the envelope load. In the southeastern United States, substantial heating equipment is often not required due to the heat produced by the machinery. The lighting load should be considered in detail, especially if the lighting is powered on for seven days a week, 24 hours a day. The number of people who occupy the areas containing the blown film equipment must also be considered. Lastly, any other miscellaneous heating or cooling inducing items must be considered, such as forklifts or break areas with stoves and coffee pots.

Initial site inspection

The ventilation engineer should first inspect the area in which the blown film line(s) is (are) located. She must determine the number of wall openings. She must determine whether the space under a negative or positive pressure and how much air is moved into or out of the space. She must inspect to determine if there is any smoke production and if carbon monoxide levels are a problem. The production line electrical loads must be determined.

Once an initial assessment has been made of the area, the ventilation engineer should convert the number of amperes drawn by the production equipment into in the equivalent number of British thermal units (BTUs). A diversity factor must be assumed to compensate for production schedules. For instance, a production facility with four blown film lines may operate only three at a time with one line undergoing maintenance at any given time. The diversity factor in this case would be .75.

Lighting load

The lighting load can be a significant factor in determining the amount of cooling and heating needed for a specific facility. Lighting will obviously add heat to an area. During the cooling season, the amount of electrical load drawn by the lighting fixtures will generally be constant for the amount of time the lighting is operated. The amount of heat produced is primarily dependent upon the wattage of the fixture. To determine the amount of heat produced by the fixture, multiply the wattage times 3.41 (BTUs per watt) times a correction factor to account for ballast variation. A correction factor of 1.20 is recommended for general applications [5].

Equation 1: $$q = 3.41 * W * CF$$

q = total heat produced (BTUs per hour)

3.41 = conversion factor, Watts to BTUs

W = total installed wattage

CF = correction factor (generally = 1.2 for fluorescent fixtures)

The total heat produced may be multiplied by the number of hours of operation during the time the ventilation systems are operating. Typically, the heat load will add to the air conditioning costs in the summer time, and reduce the requirements for heating in the winter time. When obtaining the fixture count to calculate total wattage, the designer should also consider the amount and quality of lighting in the space. If too much lighting is provided based upon foot –candle measurements, fixtures may be removed to reduce energy costs.

People load

The ventilation engineer must consider the number of employees occupying the space under consideration. Each employee will add a sensible and a latent heat load to the space. Typical factors based upon moderate activity are 200 BTUs per person per hour for a latent load and 250 BTUs per person per hour for a sensible load [5]. The simply multiply the number of people in the space by 450 to get the heat load per hour.

In addition, the American Society of Heating and Refrigerating and Air-conditioning Engineers (ASHRAE) Standard 62.1 requires ventilation air based upon occupancy [6]. The Standard provides recommended ventilation rates based upon facility usage, but 10 to 20 ft^3 per minute are generally needed. If there are other air contaminants produced in the area, such as smoke produced by the extruders, additional ventilation and air is required. The sensible heat load due to ventilation may be calculated by multiplying 1.10 times the cubic feet per minute of air required times the temperature difference between the inside and outside temperatures [6].

Equation 2: $$q = 1.1 * CFM * (T_{out} - T_{in})$$

q = total heat produced (BTUs per hour)

1.1 = correction factor for air density

CFM = cubic feet per minute of ventilation air

$(T_{out} - T_{in})$ = temperature difference

The latent load may be calculated by Equation 3 [6]:

Equation 3: $$q = 4840*(W_{out} - W_{in}) * CFM$$

q = total heat produced (BTUs per hour)

4840 = correction factor

CFM = cubic feet per minute of ventilation air
$(W_{out} - W_{in})$ = humidity difference

The total ventilation load is the sum of the latent and sensible heat produced.

Envelope load

The first the first step to determine the envelope load is to obtain the measurements of the building dimensions. The square footage of each wall section and each roof section must be computed. The type of construction of each section must then be noted to obtain the conductivity factor (U) for each section. The heat infiltration for each section may then be computed using Equation 4. The total calculation will include the sum of the heat infiltration for all wall sections and roof sections [6].

Equation 4: $$q = A * U * (T_{out} - T_{in})$$

q = total heat infiltration (BTUs per hour)

A= Exterior wall or roof section sq footage

U = Conductivity factor of wall or roof section (from tables)
$(T_{out} - T_{in})$ = temperature difference

Other considerations

Other sources of heat which may be considered are forklifts, resin dryers, break area appliances, ancillary equipment to the extrusion lines. The difficult task to determine the heat load from forklifts and break area appliances is to consider the diversity of operation. The forklifts for instance, are generally not continuously operating. The designer must consider the actual runtime of the forklift during the cooling season multiplied by the fuel consumption in BTUs per hour. Air leakage is another major consideration. Heat gain due to air infiltration may be calculated using the same methodology for determining the heat gain due to heat gain.

Example design

As an example, the air conditioning load for a hypothetical blown film plant will be computed. The design data for this plant is 93°F outside temperature and 78°F inside temperature. The building dimensions are 300 feet in length, 100 feet wide and 30 tall. Only the east wall is exposed to the outside. The other three walls are interior walls to other manufacturing departments which are air-conditioned. There are no currently existing HVAC units for this plant. It has a flat membrane roof. The exposed exterior wall is built of standard red brick facing on concrete block walls. There are 12 full time employees and six part-time employees. There are 16,560 W of florescent lighting. There are several blown film lines in this plant with multiple extruders on each line. The ampere meters read:

Line 1: 150 amps

Line 2: 300 amps

Line 3: 200 amps

Line 4: 300 amps

Line 5: 20 amps

There is one 70 horsepower, liquid propane fueled forklift which operates in the space for about four hours each eight hours of plant operation. There are about 250 CFM of outside air infiltration into the space under consideration. A summary of the observed loads is [6]:

1. Production line load is 950 amps (20% diversity). Power factor of 0.85, three phase, 480 V.
   950 amps * 460V * 3.41 BTU/W*.85 * 1.73 = 2,191,295 BTU/hr

2. Exterior wall section of 9000 square feet area, U factor from tables of 0.429.
   q = A * U * (T_{out} - T_{in}) = 9000 * 0.429 * 15 = 57,780 BTU/hr

3. Total roof area of 30,000 ft.^{2} area, U factor of 0.211 from tables.
   q = A * U * (T_{out} - T_{in}) = 30,000 * 0.211 * 15 = 94,950 BTU/hr

4. Total lighting load of 16,560 W.
   q = 3.41 * W * CF = 3.41*16,560*1.2 = 67,764 BTU/hr

5. 15 personnel on-site average.

   15 * 450 BTU/person/hr = 6750 BTU/hr

6. 250 CFM outside air infiltration. 40% humidity difference.

   Sensible load : q = 1.1 * CFM * (T_{out} - T_{in}) = 1.1*250*15 = 4125 BTU/hr

   Latent load : q = 4840*(W_{out} - W_{in}) * CFM = 4840 * 0.40 *250 = 484,000 BTU/hr

7. 70 hp miscellaneous load.

   70 hp * 2545 BTU/hp/hr *0.5 = 89,075 BTU/hr

8. Total: 2,927,975 BTU/hr = 244 tons of cooling, buy 250 tons

The ventilation calculation here will provide for temperature control in the plant during summertime when outside dry bulb temperatures are 93°F and below. When the outside temperature exceeds 93°F, the plant will be warmer than 78°F , and line control may be more difficult. For most of the southeast US, this could be as little as a few hours each day, for a few weeks a year. Five each, 50 tons cooling capacity machines may provide for diversity of operation.

The discussion in this paper determined the quantity of plant cooling required for a hypothetical blown film manufacturing operation in the southeastern United States (US). The southeastern US has four annual seasons requiring that heating and cooling loads be considered, but only the cooling load was calculated here. Many blown film plants which continuously operate in the southeast do not require substantial winter heating because the extruder heaters produce heat, over 2,000,000 BTUs per hour in our example. The ventilation load calculation considered the connected horsepower of the production machinery, the type construction of the building envelope, the number of employees in the manufacturing area, lighting and other heat producing equipment in the same space.

CONCLUSION

Heating, cooling and ventilation equipment is expensive to purchase and to operate, but process stability and employee satisfaction are two major benefits to be realized. A properly designed system is the one which will create the required environment at the cheapest cost. Following the basic design procedure described in this paper will provide the ventilation engineer a simple recipe for success. A typical ventilation load calculation will consider the connected horsepower of the production machinery, the type construction of the building envelope, the number of employees in the manufacturing area, lighting and any other heat producing operation in the same space.
Reduced scrap rates, happier employees, reduce raw materials costs, and a better quality, more consistent product could be the results.

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