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Chemical Engineering Issues In Mushroom Farming: A Case Study

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ABSTRACT

In this paper the performance of a mushroom farm is analysed section wise and some chemical engineering issues are investigated. It is found that about 80% of the total production cost goes towards energy consumption. To reduce the energy consumption and for improving the performance and efficiency, these issues are needed to be solved. Here some useful suggestions are also given for solving these issues which will reduce the total production cost and increase the profit.

KEYWORDS

Spawn;
Mycelium;
Vapour absorption refrigeration machine;
Canning;
Cooling tower.

INTRODUCTION

Growing of mushrooms in commercial scale was started in 1867. Now the world production of mushroom is about 1 million MT per year. In early seventies, mushroom cultivation was started in India on a commercial scale. Mushroom production in India is estimated to be about 10,000MT per year. However the Ministry of food processing expects the production to grow to 25,000MT per year over the next three years[1].

Commercial mushroom cultivation is carried out through out the year. Thus the constant climatic and nutrient condition for growing of mushroom is provided round the year. During cultivation, a high Relative Humidity(RH) and low temperature is required. So mushrooms are cultivated inside the growing rooms. To maintain uniform climatic conditions (humidity and temperature) inside the growing rooms chilled water supply and proper air distribution system are required. This gives rise to many chemical engineering issues including humidification, air conditioning refrigeration and fluid flow etc.

The aim of this report is to analyse the performance of a mushroom farm. About 80% of the total production cost goes towards energy consumption. The main areas are conditioning the air and its uniform distribution, canning and vapour absorption system. So a case study has been made and chemical engineering issues are identified with probable modification, which may lead to the improvement in the efficiency of the plant.

Process description

The block diagram of the entire process in mushroom growing farm is shown in figure 1. The process consists of:

i. Preparation of raw materials.
ii. Growing of mushrooms in growing rooms.

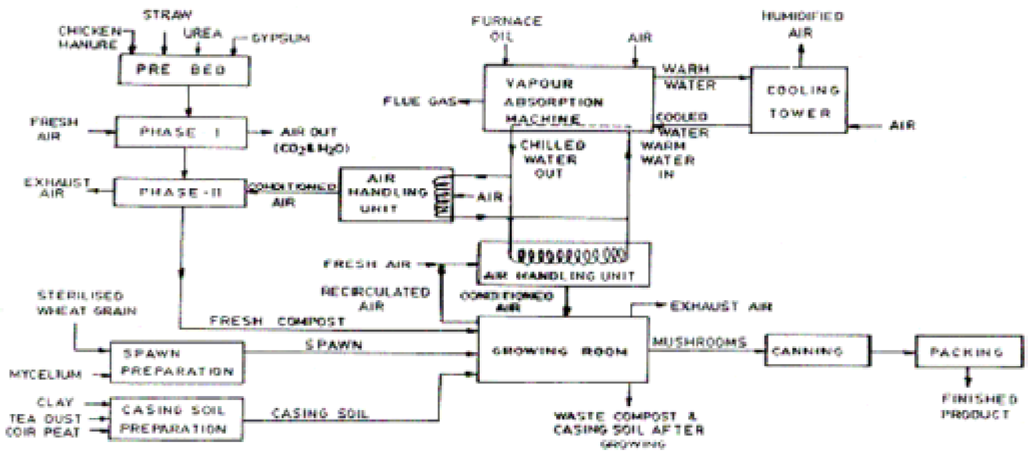

Figure 1 : Block diagram of the entire process in a mushroom growing farm

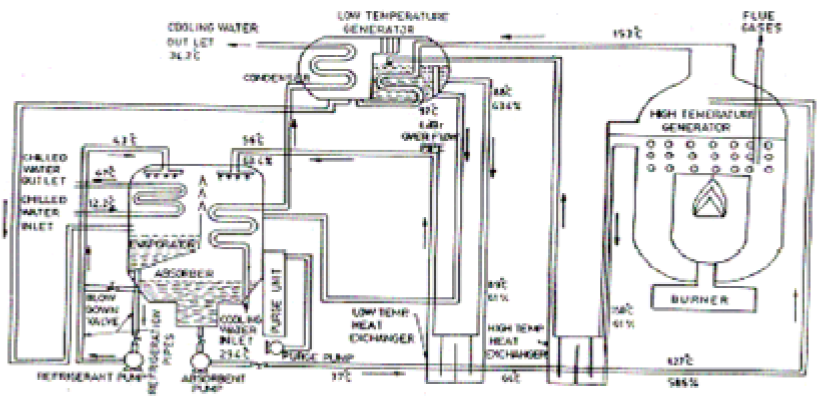

Figure 2 : Vapour absorption machine

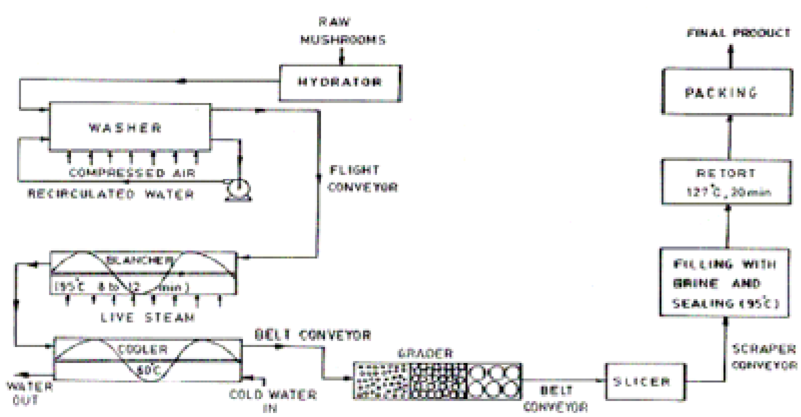

Figure 3 : Flow diagram of canning sction

iii. Canning of mushrooms.

Preparation of raw materials

The compost is prepared in three steps; pre-bed, phase-I and phase-II. At different steps different climatic conditions are maintained. The spawn is prepared by allowing the mycelium to grow in sterilized wheat grains.

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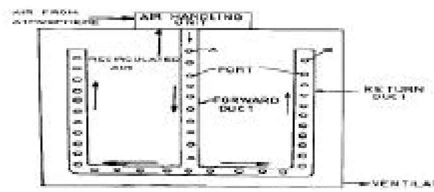

Figure 4(A) : Air distribution system in growing room

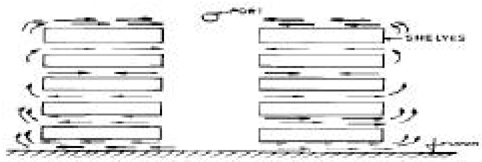

Figure 4(B) : Direction of air movement in growing room

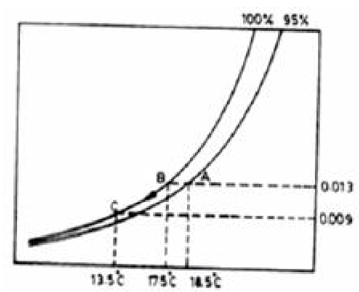

Figure 5 : Change of conditions of air(in an A.H.U.) on a humidity chart

Growing of mushrooms in growing rooms

There are 32 numbers of growing rooms of semi cylindrical shape of 28m length and 12m diameter. In every room there are four racks with five shelves each. The length and width of the racks are 24m and 1.5m respectively. The spawn is mixed with compost and spread on the racks. For the growth of mycelium a temperature of 24 to 25^{0}C, RH greater than 95% and CO_2 concentration greater than 8,000ppm is required. Under these conditions the mycelium grows inside the compost and when it reaches the surface of the compost, a layer of casing soil is spread then it grows inside the casing soil. At this stage the climatic conditions are changed to RH 95% and CO_2 concentration 800ppm. These conditions are maintained for six to seven days. A pin like structure (pin heading) appears at the top of the mycelium on the surface of casing soil. At this stage the climatic conditions are changed to a temperature of 17 to 18^{0}C and RH 80%. Under these conditions the pins grow to full mushroom. The crop of mushroom is taken in three stages over a period of about 30days.

After that, the waste compost and casing soil is removed and the room is cleaned. The room is cooked out with steam; then it is ready for the next batch. This cycle goes on. One cycle takes approximately 62 days.

To maintain a low temperature inside the growing rooms, cold air is supplied from vapour absorption refrigeration machine. For proper functioning of vapour absorption refrigeration machine, cooling water needs to be circulated. For this purpose cooling towers are needed (Figure 2).

Canning of mushrooms

The mushrooms are then sent to the canning section. In this section first the air is removed from the mushrooms and absorption of water therein is done in a hydrator then it is washed. The washed mushrooms are then exposed to water at 95^{0}C for 8 to 9 minutes to inactivate the enzymes present in it in a blancher. Then the mushrooms are cooled and size grading is done. Finally these are preserved in sealed cans under a solution of 2% NaCl and 0.2% citric acid (Figure 3).

Chemical engineering issues

Chemical engineering issues that arise in the entire process are:

- Maintaining different climatic conditions inside the growing rooms at different stages.
- Conditioning a large quantity of air and its uniform distribution inside the growing rooms.
  - Chilled water supply system.
  - Reducing the losses in canning.
  - Efficient working of cooling towers.

Growing room

(i) In the growing rooms it is observed that the CO_2 concentration does not reach up to 8,000ppm during pin heading period. It is due to the high ratio of gross volume of the growing room to cultivation area. Typically, mushrooms are cultivated in quite small rooms with a gross volume of only 1.5 to 1.8m^3 per m^2 cultivation area[2]. Presently in a growing room the cultivation area is 545m^2 and volume of the growing room is 1583 m^3. So the ratio of gross volume to cultivation area is 2.9, which is quite high. To make this ratio 1.8 around 30 shelves are required per room for maintaining CO_2 concentration in the growing room.

(ii) In the existing situation it is found that the production of mushrooms in different racks is different although the composition of compost, quality of spawn and casing soil is same every where. However, the speed of air over the bed is not uniform and varies from 66cm/s to 0.06cm/s. At high air velocity massive pin heading followed by the growth of too many smaller mushrooms and at low air velocity the mycelium will grow without any pin heading will occur[3]. So this may be the cause for uneven population of mushrooms in different racks.

At present an air distribution system is there with blowing capacity 15,000m^3/hr. By an anemometer the velocity is measured at different parts of the room and it is found that it hits the floor at a velocity of 2m/s at a point 'A' and 0.2m/s at point 'B'(Figure 4A). According to the literature the required ventilation should be 22.5m^3/hr/m^2 of growing area[4] with the maximum allowable air speed in the main duct 4m/s[5] and it should hit the floor at an average velocity of 0.45m/s. So a modified air distribution system is designed for the required air circulation of 3.406m^3/s and the diameter of main duct and port is found to be 1.05m and 8.7cm respectively. It is also suggested that short tubes(polyethylene) of about 10cm length should be fitted to the ports for a vertical flow of air from the main duct.

(iii) During the spawn run period the temperature should be 24^{0}C and RH should be greater than 95% for 14to15days. But it is observed that the RH does not reach even 90%. This is due to the fact that the air re-circulated from the growing room gets dehumidified when it flows over the coils containing chilled water(Figure 5)

The conditions of atmosphere inside a growing room which is ready for the compost loading is measured to be dry bulb temperature 28.6^{0}C, wet bulb temperature 24.8^{0}C and RH 73% and volume of air 1583m^3. From calculation it is found that the water vapour present in the air of the room is 23.165kg. But to increase the RH to 95%, 7.722 kg of water has to be evaporated before re-circulating the air through the air handling unit. But to cool the air temperature to 24^{0}C it is passed through the air handling unit where the air is passed over the coils carrying the chilled water. Here 48.78kg/hr of water condensed and the air gets dehumidified. So to keep the RH at 95% same amount of water vapour must be added. But from the literature it is found that steam can be used for humidification but not more than 15kg/hr (Van soest, 1973). So to keep the RH 95% the following methods may be used.

(1) Live steam at a rate of 15kg/hr should be introduced into the growing room.

(2) Periodic spray of warm water should be done at a rate of 34kg/hr to keep the floor wet.

(3) The spinning discs should be placed at the far end from the air handling unit.

(4) At present case the inlet air is at point 'A' in the pschyometric chart (Figure 5). Then it is cooled to point 'B'. Then the air becomes 100% saturated and follow the path 'BC'. So the air gets dehumidified. To avoid dehumidification it is only cooled to point 'B'. So the outlet temperature of the air from the air handling unit should be at a temperature of 17.5^{0}C.

(5) The water flow rate in the air handling unit should be increased but the temperature of the chilled water should not be too low. By making an energy balance it is found that the chilled water flow rate should be 8.6lit/s.

TABLE 1: Blanching losses for different size mushroom (without hydrator)

Sl. No.	Weight of fresh mushrooms(grams)	Weight of blanched mushrooms(grams)	% loss
1	6.8661	4.2063	38.738
2	7.2006	4.3615	39.428
3	6.6869	4.3254	35.315
4	6.8847	4.5887	33.349
5	17.6523	11.3172	35.888
6	21.6694	13.3702	38.299
7	28.2729	18.3705	35.024
8	32.9991	22.3371	32.309
9	44.6188	29.374	34.166

TABLE 2 : Blanching losses for different size mushroom (with hydrator)

Sl. No.	Weight of fresh mushrooms (grams)	Weight of blanched mushrooms (grams)	% loss
1	6.2273	5.1831	16.76
2	10.1743	8.5504	15.96
3	18.2051	16.3301	10.29
4	33.0899	30.1654	8.838

Canning

(i) It is observed that the feed rate of mushrooms

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TABLE 3 : Flue gas analysis on dry basis

Component present	Weight present in kg	Mole present	Mole %	Vol. %
CO_2	315.333	7.1666	13.96	13.96
SO_2	4.0	0.0625	0.0012	0.0012
N_2	1205.439	43.051	83.915	83.915
O_2	32.733	1.0229	1.99	1.99

to the washer is not uniform(it varies from 1 to 4 crates per minute) so sometimes the mushrooms get pressed inside the washer which leads to damage of mushrooms.

So for the existing line capacity(1.5tonnes/hr) it is calculated that the feed rate should be 1 crate in 24 seconds.

(ii) Presently in the blancher, same blanching time is allowed for different size of mushrooms which lead to higher blanching losses. To confirm these, two different experiments were carried out to find out the losses in different sizes of mushrooms for the same time of blanching.

(a) Without using the hydrator.

(b) Using the hydrator.

(a) For the calculation of blanching losses without using the hydrator, the tray was filled with water and its temperature was brought to 95^{0}C by blowing live steam into it. Fresh mushrooms were dipped in it for 11 minutes then the weights of these were taken and the losses were calculated (TABLE 1.).

From the above experiment it was observed that for the same time of blanching the losses in small mushrooms were higher than for bigger mushrooms and this happened due to the over blanching of the small mushroom.

(b) For the determination of blanching losses of hydrated mushrooms four mushrooms of different weight were taken and put in the actual hydrator for 15 minutes. Then these mushrooms were washed in the washer and put into the actual blancher(at 95^{0}C) for 13 minutes. Then the weight was measured after blanching(TABLE 2).

It is observed that the losses were more for the smaller mushrooms due to over blanching and by using the hydrator before blanching, the losses get reduced by approximately 70%.

So it is suggested that the mushrooms should be graded according to size by visual means during picking stage itself and mushrooms of almost equal size

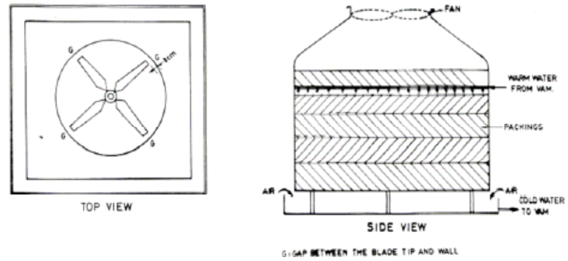

Figure 6 : Cooling tower

should be processed in the same lot at the same time the hydrator should be always used. It is calculated that the optimum blanching time for button size mushroom should be 8 minutes and sizes bigger than this, the blanching time should be 12 minutes.

(iii) It is also found that for the better efficiency of the blancher the speed of the flight conveyor (which leads from washer to the blancher) should be 0.91m/min. The present speed is 1.5 m/min.

Chilled water supply system

(i) In the high temperature generator of the vapour absorption refrigeration machine it was found that the tubes (which carry flue gases)needs cleaning every month though the supplier(Thormax) have recommended the cleaning every three month instead of each month.

So the proximate analysis of the soot formed inside the tubes of high temperature generator is done and it is found that the percentage of moisture, volatile matter, fixed carbon and ash are 3.77, 56.99, 28.61 and 10.63 respectively. From the analysis it is observed that the volatile matter and fixed carbon content in the soot is high. So the burning is not 100% completed and resulting to high soot formation and high fuel consumption. This happens due to improper fuel to air ratio.

In the vapour absorption refrigeration machine the fuel burnt is furnace oil whose composition is C-86%, H_2-12%, S_2-2%, and from the manual of Thormax it is found that the recommended excess air is 10%. So if 10% excess air is used the composition of the flue gas should be as given in(TABLE 3).

So by analyzing the flue gas the fuel to air ratio should be maintained. If O_2 present in the flue gas is more than 1.99% the air flow rate should be reduced and if it is less than 1.99% the air flow rate should be increased. Again by making a mass and energy balance for high temperature generator it is found that ideally, the fuel consumption should be 76.63 kg/hr and air requirement should be 1319 m^3/hr.

(ii) It is found that the heat loss from the refrigeration pipe, high temperature heat exchanger and low temperature heat exchanger is 20,777 Kcal/hr, 58,470 Kcal/hr and 1016 Kcal/hr respectively which is quite high.

So to improve the efficiency of the vapour absorption refrigeration machine, insulation should be provided in high temperature heat exchanger, low temperature heat exchanger and in the refrigeration pipe.

Cooling tower

In the present case the inlet water temperature to the cooling tower is 38.3^{0}C and outlet temperature is 36^{0}C. So only a drop of 2.3^{0}C is achieved though the dry bulb and wet bulb temperatures of the atmospheric air is 35.5^{0}C and 25.5^{0}C respectively. The expected drop of temperature in the existing cooling tower is 5^{0}C. So a study was made and the following were observed.

(a) The liquid to gas ratio is quite high that is 3.175(water flow rate is 320m^3/hr and air flow rate is 27.9m^3/s) but the recommended liquid to gas ratio should be in the range of 0.75 to 1.5[6] so the maximum water flow rate should be 198m^3/ hr.

(b) 16% air is short circuited at the top of the cooling tower due to the quite high gap between the blade tip and the wall(5 to 8cm). So this gap should be reduced to 1 to 1.2cm(Figure 6).

(c) The air, which is sucked from the bottom is not uniform. It's velocity ranges from 360 to 157m/ min. This is due to

(1) The uneven distribution of water at the top of cooling tower.

(2) Some of the packing materials got chocked.

(3) The distance between the two cooling towers is quite low.

(d) The hardness of the water is 1200ppm whereas the recommended hardness should be 200 ppm. This is due to the disconnection of the water softner. So the existing water softner should be taken in line.

(e) Lot of suspended impurities and fungi are found in the cooling water. This can be overcome by connecting the sand filter already available.

(f) Some of the nozzles are chocked. So time to time inspection of nozzles should be carried out.

(g) By making an overall heat balance over the vapour absorption machine it is found that 648.11 Kcal/s heat should be removed from one vapour absorption machine. But there are 3 numbers of vapour absorption machines, so the total heat to be removed is 1944.33 Kcal/s.

The existing cooling tower having the capacity 350m^3/hr and range 4.8^{0}C can remove heat of amount 446.66Kcal/s. So the number of cooling towers required to remove the heat is four. But presently three numbers of cooling towers are there which is not adequate.

CONCLUSION

In this paper description of a mushroom farm, is given. A careful study has been made to increase the production of the plant. Considering some of the chemical engineering issues modifications in the plant are suggested.

In the future these issues are to serve more investigation. From this case study it is found that the performance and efficiency of a mushroom farm can be improved by solving the chemical engineering issues. It will reduce the total production cost and increase the profit.

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