A small scale honey dehydrator

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Revised: 28 January 2015 / Accepted: 2 February 2015 / Published online: 21 February 2015
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Abstract A small scale honey dehydrator has been designed, developed, and tested to reduce moisture content of honey below 17 %. Experiments have been conducted for honey dehydration by using drying air at ambient temperature, 30 and 40 °C and water at 35, 40 and 45 °C. In this dehydrator, hot water has been circulated in a water jacket around the honey container to heat honey. The heated honey has been pumped through a sieve to form honey streams through which drying air passes for moisture removal. The honey streams help in increasing the exposed surface area of honey in contact with drying air, thus resulting in faster dehydration of honey. The maximum drying rate per square meter area of honey exposed to drying air was found to be 197.0 g/h-m² corre-

sponding to the drying air and water temperature of 40 and 45 °C respectively whereas it was found to be minimum (74.8 g/h-m²) corresponding to the drying air at ambient temperature (8–17 °C) and water at 35 °C. The energy cost of honey moisture content reduction from 25.2 to 16.4 % was Rs. 6.20 to Rs. 17.36 (US \$ 0.10 to US \$ 0.28 (One US \$ = 62.00 Indian Rupee on February, 2014) per kilogram of honey.

Keywords Drying · Dehydration rate · Moisture content · Honey · Energy consumption

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Highlights

- A small scale honey dehydrator has been developed to reduce the moisture content of honey below 17 %.
- Maximum honey dehydration rate was 197.0 g/h-m² for range of parameters investigated.
- The dehydration cost per kg of honey varied between US \$ 0.10 and US \$ 0.28 for range of parameters investigated.
- Dehydration rate was 2.89 times as compared to that of previously developed desiccant honey dehydrator.
- Energy consumption was 3.2 times less than that of the desiccant honey dehydrator.

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Introduction

Honey is the natural sweet substance produced by honeybees and derived from the nectar of blossoms or from the secretion of living parts of plants or excretions of plant sucking insects on the living parts of plants, which honeybees collect, transform and combine with specific substances of their own, store and leave in the honey comb to ripen and mature (Food And Agricultural Code Section 29413). Nearly 1.3 million tonnes of honey is produced worldwide every year and is extensively used for its nutritional as well as medicinal value (Shamala and Jyothi 1999; Randerson 2007; Fauzi et al. 2014). To use honey for the above stated purposes, it needs to be stored. Moisture content of honey is practically the most important quality parameter, as it affects storage life. If moisture content of honey is more than 19 %, it starts to ferment, to spoil, to lose flavor, to granulate irregularly and to separate into two layers during storage, thus, reduces its shelf life (Dustmann 1993). It has been reported in literature that if moisture content of honey is below 17 %, fermentation of honey will not occur irrespective of the yeast count (Wakhle 1997; Sanz et al.

1995). Therefore, it becomes imperative to dehydrate honey below 17 % moisture content for safe storage and to fetch higher price in market.

Honey is close to a Newtonian fluid containing bound as well as free moisture. Free moisture gets evaporated during honey dehydration. Various honey dehydrators have been developed for honey dehydration using hot air (Ellis 1987; Paysen 1987; Wakhle et al. 1988; Crane 1995; Platt and Ellis 1984; Thumber 2002; Alam et al. 2012) and hot water (Wakhle et al. 1996; Subramanian et al. 2007). With increase in temperature of honey, internal water diffusion increases resulting in increase in honey dehydration (Yener et al. 1987). However, application of heat has a negative effect on the quality of honey through the loss of thermolabile and aromatic substances. Heating process also darkens the honey (Subramanian et al. 2007), increases its HMF (hydroxymethylfurfural) content and decreases its enzyme (e.g. diastase) activity (Nurhadi et al. 2012; Mishra 1993). It has been reported in literature that adverse effect of heating on quality of honey is proportional to the temperature and the duration for which heat is applied to it (Crane 1995; White 2000). To avoid deterioration of honey quality, it has been reported that honey should not be heated above 45 °C (Skinner 2009). In order to decrease the duration of honey exposed to heat, a number of systems have been reported in literature such as, horizontal rotating drum (Platt and Ellis 1984), inclined trays (Paysen 1987; Maxwell 1987; Kuehl 1988), cones (Wakhle et al. 1988), perforated trays (Crane 1995) etc. In these systems, enhanced surface area of honey in contact with drying air was used for faster drying. Investigators have also tried vacuum drying for faster drying of honey at temperature less than 45 °C (Shamala and Jyothi 1999; Wakhle et al. 1996). However, vacuum drying results in a significant loss of honey aromatics and flavonoids which are stable at normal atmospheric pressure (Cui et al. 2008). Dehumidifiers to reduce the relative humidity of air have also been used to dehydrate honey (Glen 1991; Nass 1986; Dziadyk 2004). It has been suggested that relative humidity, less than 59 % is required to achieve 18 % moisture content of honey (Murrell and Henley 1988).

On the basis of literature review, it can be concluded that dehydration rate of honey is a function of honey temperature, temperature and humidity of drying air as well as surface area of honey exposed to drying air. Adverse effect of heating on quality of honey is proportional to the temperature and the duration for which heat is applied to it.

Keeping above in view, a small scale honey dehydrator has been designed, fabricated and tested with an aim to enhance dehydration rate by increasing the surface area of honey exposed to drying air. In this system, surface area of honey exposed to drying air has been increased by using a sieve which broke the honey into number of small diameter streams. The method used in this honey dehydrator for increasing the

exposed surface area of honey has been found to be cheaper as compared to other method reported in literature (Singh et al. 2011). The increased dehydration rate resulted in reduction in exposure time of honey to heat which affected the quality of honey favorably.

Materials and methods

System description

The honey dehydrator consists of honey heating system, honey recirculation system, moisture removal chamber, air heating and circulation system. The schematic details of the honey dehydrator have been shown in Fig. 1. Initially, honey to be dehydrated is loaded in a container which is placed just below the moisture removal chamber. The honey loaded in the container is then heated by circulating hot water in a jacket around the honey container to desired temperature level. When desired temperature of honey is attained, then honey is pumped to the top of the moisture removal chamber where a sieve has been placed to break the honey in to streams. These honey streams are allowed to fall through the moisture removal chamber in the honey container. At the same time, drying air at desired temperature is passed across honey streams for moisture removal. The honey collected in honey container is then re-circulated through moisture removal chamber for further dehydration to achieve desired moisture content.

The major components of honey dehydrator viz. honey heating system, honey re-circulation system, moisture removal chamber, air heating and circulation system are described below in details:

Honey heating system

The honey heating system consists of a honey container, hot water jacket and hot water re-circulation system as shown in Fig. 1.

Honey container Honey container is made of twenty four gauge thick galvanized iron (G.I.) sheet of rectangular cross-section having dimensions 37.6 cm × 20 cm × 35 cm. It can hold about 20 kg of honey. An outlet is provided at the bottom of this container and is connected to honey pump to facilitate re-circulation of honey. The honey container is placed directly below the moisture removal chamber and is surrounded by a hot water jacket.

Hot water jacket Hot water jacket is made of GI sheet having dimensions 48.5 cm × 30.5 cm × 30.5 cm. The water jacket is placed around honey container and hot water is circulated through the annular space between water jacket and the honey container for heating honey. For circulation and uniform

Fig. 1 Schematic details of small scale honey dehydrator

distribution of hot water around the honey container, three inlets and three outlets of hot water are provided on the opposite sides of water jacket wall. The height of hot water inlets and outlets are 4 and 25.5 cm respectively. To reduce heat loss, the water jacket is insulated on all sides and bottom with 5 cm thick thermocole.

Hot water circulation system The hot water re-circulation system consists of hot water tank, electric heater, water pump and connecting pipes as shown in Fig. 1. A small hot water tank 24 cm × 28 cm × 28 cm is fixed on the side of water jacket for continuous supply of hot water to water jacket at specified fixed temperature. The temperature of water in water jacket is maintained at desired temperature with thermostatically controlled, 1.75 kW, electric heater fixed in hot water tank. The hot water is re-circulated through hot water tank and water jacket with the help of 0.18 kW centrifugal water pump having 2800 rpm speed. To reduce heat loss, 5 cm thick thermocole is provided on all sides of the water tank.

Honey re-circulation system

For re-circulation of honey from the honey container to the moisture removal chamber, 1.03 kW gear honey pump having capacity of 25 LPM and 1440 rpm speed, has been used. In order to control the flow rate of honey, a valve is fixed before honey pump. A drain port with valve has been provided after honey pump to drain honey after each test run.

Moisture removal chamber

Moisture removal chamber, made of GI sheet and having dimensions 37.6 cm × 20.0 cm × 45.0 cm, has been placed and fixed on top of the honey container. For the formation of

honey streams in moisture removal chamber, a sieve (Fig. 2a), having cross-section of 36.5 cm × 19.5 cm and 5.0 cm depth, is placed on the top of moisture removal chamber. The sieve has 122 uniformly spaced holes of 0.5 cm diameter that break heated honey into streams as shown in Fig. 2b. The breaking of honey into streams results in increasing the exposed surface area of honey in contact with drying air. The total surface area of honey exposed to drying air in moisture removal chamber was 1.11 m². In order to monitor the level of honey above sieve, a transparent cover has been provided at the top of the sieve. Provisions have also been made in the transparent cover for measurement of honey temperature as well taking of honey sample for measuring its moisture content.

Air heating and circulation system

A three phase, 0.16 kW, centrifugal air blower having speed of 2400 rpm has been used to supply drying air to the moisture removal chamber. Air supplied to the moisture removal chamber is heated with the help of a thermostatically controlled, 1.70 kW, electric heater. Air enters the moisture removal chamber through one of the vertical sides and leaves through the opposite side. For uniform distribution of air around honey streams, a wire mesh, having an aperture opening of 2.85 mm, is fixed at air inlet of moisture removal chamber. To measure flow rate of air, an orifice plate having 5 cm throat diameter has been fixed in a 10 cm air pipe. A U-tube manometer having water as a manometric fluid has been used to measure pressure difference across the orifice plate.

It may be noted that in this prototype honey dehydrator, GI sheet was used only for performance evaluation purpose. But for actual use of honey dehydrator, it is suggested that parts of

Fig. 2 **a** Sieve **b** Formation of Honey Streams in moisture removal chamber

honey dehydrator which come in contact with honey should be made of stainless steel.

Experimental procedure

For testing of honey dehydrator, about 20 kg of honey (Himalayan multifloral variety) was loaded in the honey container. The honey was heated and maintained at constant temperature by circulating hot water in water jacket around honey container. When constant temperature of honey was attained, honey pump was turned ON to re-circulate honey for formation of honey stream in the moisture removal chamber. Simultaneously, the air blower and electric heater were also switched ON to blow air at desired temperature through honey streams in moisture removal chamber. The air flow rate through moisture removal chamber was 1.98 m³/min. As the drying proceeds, honey gets more and more viscous which results in decrease in flow rate of honey. This causes fall in level of honey above the sieve which adversely affects stream formation. For proper formation of honey streams during drying, desired level of honey above the sieve was maintained by adjusting flow rate of honey. The above drying procedure was continued till moisture content of honey was brought below 17 %.

To evaluate the performance of the honey dehydrator, different tests were carried out with drying air at 30 °C, 40 °C and ambient temperature for each hot water temperature of 35, 40 and 45 °C.

During the test runs, inlet and outlet air temperatures, honey temperature in honey container, and water temperature in water jacket were measured with the help of calibrated copper-constantan thermocouples. A digital honey refractometer was used to measure the moisture content of honey on wet basis (w.b.) and relative humidity of ambient air was measured with a digital hygrometer. All the above mentioned operating

parameters were recorded after every half an hour. During a test run, energy consumed by air blower, honey pump, water pump, air and water electric heaters were recorded with energy meters. The dehydration rate was determined using following equation (Chakraverty 1988).

$$R = \frac{\frac{(m.c._1 - m.c._2)}{(100 - m.c._2)} \times W_1}{t} \quad (1)$$

Where, R - Dehydration rate, kg/h

m.c.₁ - Initial moisture content, percent, (w.b.)

m.c.₂ - Final moisture content, respectively, percent, (w.b.)

W₁ - Initial weight of honey loaded, kg

t - Drying time, h

Uncertainty in results

The uncertainty analysis based on precision of the equipments used during experimentation has been carried out. The uncertainty has been calculated on the basis of the uncertainty in the measurements of all the related independent variables (Holman 2004). The uncertainty in measurement of air flow rate, energy, weight of honey, time, moisture content of honey, relative humidity and dehydration rate has been found to be ±1.69, ±0.19, ±0.048, ±0.0019, ±0.041, ±1.32 and ±0.75 % respectively.

Results and discussion

The results obtained for all combinations of operating parameters have been given and discussed below:

Fig. 3 Variation of moisture content of honey with drying time corresponding to test run numbers 1, 2, and 3

Effect of Water Temperature

Figures 3, 4 and 5 show the effect of water temperature on drying time for drying air at ambient temperature, 30 and 40 °C respectively to reduce the moisture content of honey below 17 % from its initial values. The corresponding values of dehydration rate are shown in these figures. It is clear from Figs. 3, 4 and 5 that drying time decreased while dehydration rate increased with increase in water temperature from 35 to 45 °C for same initial and final moisture content. The increase in dehydration rate due to increase in internal water diffusion caused by increase in honey temperature was also reported by Yener et al. (1987).

Effect of air temperature

In order to bring out the effect of temperature of drying air on drying time and dehydration rate of honey, Fig. 6 has been

drawn for drying air at ambient temperature, 30 and 40 °C when water was maintained at 40 °C temperature. It has been found that as the air temperature increased, drying time decreased and the dehydration rate increased (Fig. 6). It is due to the fact that when low temperature air comes in contact with honey, temperature of honey reduces, thereby, affecting the drying time and dehydration rate adversely. With increase in air temperature, loss of heat from honey was less which resulted in decrease in drying time and increase in dehydration rate. Similar effect of air temperature was observed for water temperature values of 35 and 45 °C.

From above discussion, it can be concluded that maximum dehydration rate of honey was 218.7 g/h corresponding to the maximum water and air temperature values of 45 and 40 °C respectively. The minimum dehydration rate of honey was 83.0 g/h for water at 35 °C and air at ambient temperature.

Fig. 4 Variation of moisture content of honey with drying time corresponding to test run numbers 4, 5, and 6

Fig. 5 Variation of moisture content of honey with drying time corresponding to test run numbers 7, 8, and 9

Activity of water

Water activity has been estimated for honey used in this experimental study on the basis of final moisture content by using different correlations reported in literature (Ruegg and Blanc 1981; Chirife et al. 2006; Zamora et al. 2006; Abramovic et al. 2008). The range of activity of water obtained from the correlations was between 0.55 and 0.58 for all the test runs which has been found to be less than the limiting value of activity of water (0.60) at which honeys are microbiologically stable (Ruegg and Blanc 1981; Beckh et al. 2004).

Energy consumption

Total energy consumed to reduce moisture content of honey below 17 % under different test runs has been given in Table 1. It has been observed from the data recorded for energy consumption that heating of air consumed a major portion of energy and it varied between 35 and 62 % of the total energy consumption except for test runs 1, 2 and 3 in which air was not heated. The minimum and maximum values of total energy consumed have been found to be 18.5 and 53.2 kWh corresponding to test runs 3 and 7 respectively. It is due to the fact that during test run 3, there was no air heating which otherwise

Fig. 6 Variation of moisture content of honey with drying time corresponding to test run numbers 2, 5, and 8

Table 1 Total energy consumption and honey temperature for each test run

Test run	Drying air temperature at inlet of the moisture removal chamber (°C)	Water temperature in water jacket (°C)	Honey temperature (°C)	Total energy consumed for dehydration of honey (KWh)
1	Ambient Temperature (8–17)	35	22–29	30.5
2	Ambient Temperature (7–17)	40	21–29	32.6
3	Ambient Temperature (17–21.5)	45	30–35	18.5
4	30	35	22–32	34.0
5	30	40	27–32	39.3
6	30	45	30–34	32.2
7	40	35	22–34	53.2
8	40	40	24–32	38.0
9	40	45	26–38	32.4

consumed major portion of energy whereas in case of test run 7, air was heated to 40 °C resulting in increase in energy consumption.

The operating cost per kilogram of honey of the system for each test run has been determined on the basis of grid electricity cost of Rs. 7/kWh (US \$ 0.11 considering the conversion rate of one US \$ equal to 62.00 Indian Rupee as on February, 2014) for Punjab (India). Minimum and maximum operating costs per kilogram of honey were found to Rs. 6.20 (US \$ 0.10) and Rs. 17.36 (US \$ 0.28) corresponding to test runs 3 and 7 respectively. Under optimum conditions the dehydration cost for one kilogram of honey was found to be Rs. 9.92 (US \$ 0.16) corresponding to test run number 9.

Comparison with previous system

The performance of the present system has been compared with honey dehydrator reported in literature (Singh et al. 2011) under similar operating conditions. The comparison has been carried out in terms of dehydration rate per square meter area of honey exposed to drying air, energy consumption and operating cost for drying one kilogram of honey.

For the developed small scale honey dehydrator, maximum dehydration rate, energy consumption and operating cost for drying one kilogram of honey has been found to be 8.93 g/h-m², 1.45 kWh and US \$ 0.16 respectively for drying air

temperature of 40 °C and honey temperature range of 26–38 °C. In case of desiccant honey dehydrator, the corresponding values are 5.62 g/h-m², 2.10 kWh and US \$ 0.23 respectively for drying air temperature range 28–35 °C and honey temperature of 40 °C. Therefore, the present system not only dehydrated honey at a faster rate but also at a lesser cost.

The comparative performance of both the honey dehydrating systems under similar operating conditions has also been evaluated and has been shown in Table 2. It has been observed that dehydration rate of the present system is 2.89 times that of the desiccant honey dehydrator. The increase in dehydration rate of the present system is on account of increase in the exposed surface area of honey in contact with drying air which is achieved by forming the honey streams and making drying air to flow across the honey streams. The operational energy consumption of the present system has been found to be 3.2 times less than that of the desiccant honey dehydrator, thereby resulting in lower operating cost in case of the present system.

Conclusions

A small scale honey dehydrator has been designed, fabricated and tested to reduce the moisture content of honey below 17 % in order to increase its shelf life. The honey was heated below

Table 2 Comparison of present system with desiccant honey dehydrator (Singh et al. 2011) corresponding to test run number 3 for drying one kilogram of honey

Honey dehydrator	Temperature of drying air (°C)	Relative humidity of drying air (%)	Temperature of honey (°C)	Reduction in moisture content of honey (%)	Dehydration rate (g/h-m ²)	Energy consumption (KWh)	Operating cost (US\$)
Present system	Ambient temperature (17–21 °C)	40–76	30–35	25.3 to 16.0	7.67	0.94	0.10
Desiccant honey dehydrator	Ambient temperature (17–24 °C)	37–72	35	27.3 to 17.2	2.65	2.90	0.32

maximum permissible temperature to maintain its quality. The dehydration rate of honey has been found to be strong function of drying air and honey temperature. Maximum honey dehydration rate of 197.0 g/h-m² has been achieved corresponding to the maximum temperature values of 26–38 and 40 °C for honey and air respectively. The dehydration cost for one kilogram of honey was found to vary between Rs. 6.20 (US \$ 0.10) and Rs. 17.36 (US \$ 0.28). Under optimum conditions the dehydration cost for one kilogram of honey was found to be Rs. 9.92 (US \$ 0.16). Under similar operating conditions, the performance of the present system has been found to be better than desiccant honey dehydrator reported in literature. The dehydration rate of the present system was found to be almost 2.89 times that of the desiccant honey dehydrator. For the present system, the operating cost was 3.2 times less than that of the desiccant honey dehydrator.

Acknowledgments The authors are grateful to Indian Council of Agricultural Research (ICAR) for funding this project.

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