J. agric. Engng Res. (1992) **51**, 15–27

Mixed Convection About Fruits

LIANGYOU TANG; ARTHUR T. JOHNSON

Agricultural Engineering Department, University of Maryland, College Park, MD 20742, U.S.A.

(Received 30 April 1990; accepted in revised form 27 April 1991)

Mixed convection conditions may exist when cooling field-fresh fruits. Experiments to determine convection coefficients were performed on cast models of apple, peach, plum, and strawberry shapes. Mixed convection Nusselt numbers were found to be obtainable from those for pure forced and natural convection.

1. Introduction

Freshly harvested fruits and vegetables are often immediately cooled to reduce spoilage. Cooling is accomplished by forcing cold fluid over them, but the combination of relatively weak forced flow and very warm objects can result in mixed forced and natural convection for fruits and vegetables. Compared to either extreme of wholly forced or natural convection, mixed convection processes are not well understood. Knowledge of mixed convection coefficients are essential for the design of heat loads for refrigeration units and for improvements in systems designed to reduce spoilage.

We have performed intensive experimental investigations on the subject of mixed convection about a sphere[1–4] and have found that the heat transfer rate is a function of several factors. Among them, the forced airflow velocity (represented by the Reynolds number), the temperature difference (represented by the Grashof number), and the angle between forced airflow and natural airflow were the most important factors. The results of that research showed that there were mainly three data regions occurring with different angles: an aiding to cross flow region; a transition region; and a counter flow region. In aiding flow, forced convective flow and natural convective flow travel in the same direction. In counter flow, the two components oppose each other. In cross flow, forced air flows horizontally and natural convective air rises, forming an angle of 90° between them. This study was concerned only with the cross flow case.

The Effective Diameter Scalar Addition (EDSA) method was developed to correlate experimental data for aiding and cross flows for a sphere.[1–4] Using this method, mixed forced and natural convection Nusselt numbers were determined for the entire aiding flow to cross flow regime. Counter flow could be treated the same way.

The EDSA method is based upon concepts proposed by Kirk[1] to describe flow patterns around the sphere and the ways in which these determine forced and natural convection heat losses. Especially interesting is the fact that the Nusselt number was found to be related to projected vertical distance of the sphere in addition to other geometrical and physical properties determining Reynolds and Grashof numbers.

The EDSA method is as follows:

1. An effective diameter[2] is found from:

$$d_{\text{eff}} = d[\alpha - (2/\pi) \cos \phi \tan^{-1} (\text{Re}/\text{Gr})] \tag{1}$$

Scientific Article Number A6013, Contribution Number 8173 of the Maryland Agricultural Experiment Station (Department of Agricultural Engineering).

0021-8634/92/010015 + 13 $03.00/0

© 1992 Silsoe Research Institute

Notation

A, B	offset in equations for irregular spherical object, dimensionless
d	real diameter for sphere, characteristic diameter for fruit shaped object, m
d_i	diameter of largest inscribed circle of an irregular spherical object, m
d_c	diameter of smallest circumscribed circle of an irregular spherical object, m
d_{eff}	effective diameter in EDSA method, m
Gr	Grashof number, dimensionless
Gr*	effective Grashof number in EDSA method, dimensionless
g	gravitational constant, 9·81 m/s^2
m, n	coefficient in pure natural and forced convection equations, respectively, dimensionless
Nu	Nusselt number, dimensionless
p, q	exponent in pure natural and forced convection equations, respectively, dimensionless
Re	Reynolds number, dimensionless
Re*	effective Reynolds number in EDSA method, dimensionless
Re_{eq}	equivalent Reynolds number in EDSA method, dimensionless
t_s	object surface temperature, °C
t_a	free stream air temperature, °C
α	effective diameter parameter, dimensionless
β	coefficient of thermal expansion of air, l/K
ϕ	angle between forced and natural flow, radian
ν_f	kinematic viscosity of air at mean film temperature, m^2/s

The value for α was between 0·9 and 1 in the sphere case, depending on the Grashof number.[3,4] A value of 1·0 has been used in the analysis presented later in this paper.

2. An effective Grashof number then becomes:

$$Gr^* = \frac{g\beta d_{eff}^3(t_s - t_a)}{\nu_f^2} \tag{2}$$

3. The equivalent Reynolds number is a fictitious parameter that, when inserted into the forced convection Nusselt number equation, gives the correct value of Nusselt number for natural convection. The equivalent Reynolds number facilitates calculation of the mixed convection Nusselt number. To find an equivalent natural convection Reynolds number, the general empirical formula for forced convection is assumed to be:[1–4]

$$N = m\, Re^q \tag{3}$$

and the general equation for natural convection was assumed to be:

$$N = n\, Gr^p \tag{4}$$

Inserting Eqn (2) and setting Eqns (3) and (4) equal to each other to obtain an equivalent Reynolds number, we obtain:

$$Re_{eq} = (n/m\, Gr^{*p})^{1/q} \tag{5}$$

4. The equivalent natural convection Reynolds number is combined with the forced convection Reynolds number by scalar addition to get an effective mixed convection Reynolds number:

$$Re^* = Re_{eq} + Re \tag{6}$$

5. Finally, a mixed convection Nusselt number is obtained using the forced convection equation:

$$\mathrm{Nu} = m\ \mathrm{Re}^{q} \tag{7}$$

This study was intended to determine the cross flow mixed convective heat transfer coefficients for apple, peach, plum and strawberry-shaped objects, for various Reynolds and Grashof number values. This study used the EDSA method as a basis to correlate the experimental results.

2. Materials and methods

The experimental equipment consisted of a wind tunnel, several fruit-shaped objects, and measurement instruments. The wind tunnel was an open circuit low-speed wind tunnel designed to minimize turbulence (*Fig. 1*). Details of the wind tunnel, air speed measurements and temperature measurements appear in Kirk and Johnson.[2] The tunnel was positioned so that horizontal forced flow and rising natural flow around the objects formed a 90° angle (cross flow).

The fruit-shaped objects were modelled from an apple, a peach, a plum, and a strawberry. These objects were made of silicone rubber (GE RTV 700) compound cast from plaster moulds. This compound had a manufacturer-specified thermal conductivity of 0·23 W/(m . K) compared to published thermal conductivities of 0·68 W/(m . K) for strawberries and 0·42 W/(m . K) for oranges.[5] An electric heater made from nichrome wire wrapped around a ceramic core was placed in the centre of the object. The surfaces of the objects were first painted with a layer of conductive silver-based epoxy material in an attempt to minimize the surface temperature gradient. The surface was then coated with flat black paint to give a known surface emissivity of 0·92.

Mohsenin[6] defined the sphericity of a solid object as:

$$\text{Sphericity} = d_i/d_c \tag{8}$$

The fruits used in this study had sphericities of 0·888, 0·904, 0·965, and 0·791, for apple, peach, plum and strawberry, respectively. From these numbers, it can be seen that the

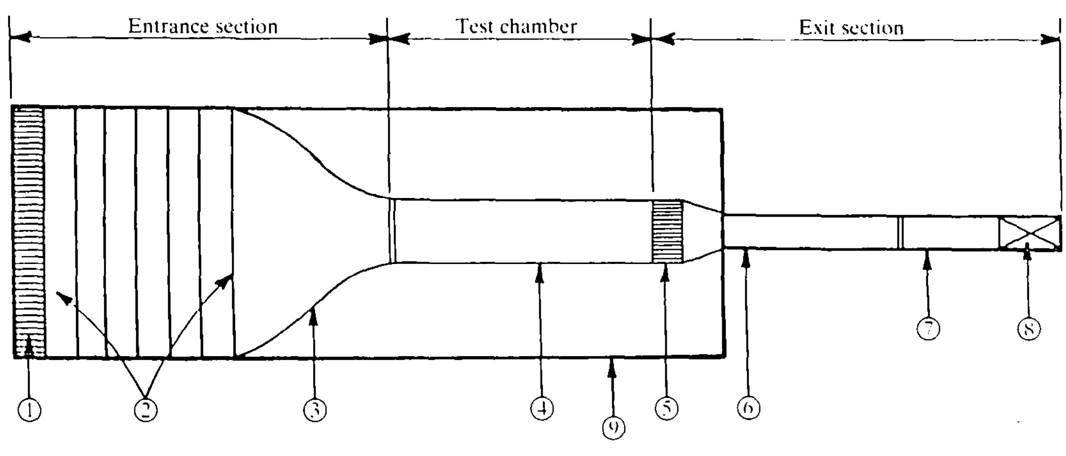

Fig. 1. Schematic diagram of the wind tunnel used in the present experiment: (1) honeycomb section, (2) screen panels, (3) contraction zone, (4) test chamber, (5) rear honeycomb section, (6) conical reducer, (7) orifice pipe, (8) fan and motor, (9) front support assembly

peach, the plum, and the apple were nearly spherical in shape, whereas the strawberry was quite unlike a sphere.

Characteristic diameters of the objects were obtained following hydrodynamics procedures.[7] First, the projected area was determined for the cross-section perpendicular to the forced airflow. Second, the projected perimeter was measured. The hydraulic radius was then obtained by dividing the projected area by the projected perimeter. The characteristic diameter was four times the hydraulic radius.[7] Through this procedure, the characteristic diameters for apple, peach, plum and strawberry were determined as 0·081 m, 0·068 m, 0·057 m and 0·040 m, respectively.

During testing, each object was suspended in the centre of the wind tunnel test chamber. Four to six thermocouples were attached to the surface of the object, depending on its size. Each thermocouple measured a representative temperature of one of four to six segments of the surface. Meanwhile, the temperature of the testing chamber wall was measured at 11 points, each of the points represented the temperature of one of the 11 wall segments. The radiation shape factors between each surface segment and related wall segments were estimated,[8] and radiation heat losses from the objects were found. Air temperature was also measured to determine air physical properties for the calculation of Reynolds number and Grashof number. Thermocouples were calibrated with a National Institute of Standards and Technology calibrated thermocouple, which has a precision of ±0·1°C. Temperature measurement was recorded by a multichannel data acquisition system.

Air velocity was calculated from the readings of a double-sided inclined manometer used to measure the pressure drop across an orifice. Barometric pressure was measured to obtain the density of the air moving through the orifice. Measurement details were described by Kirk[1] and Tang.[3]

Power input to the test sphere was supplied by a regulated d.c. power supply. Power was monitored as the voltage drop across the leads to the object heater and the current through a series resistor.

The experiment began with pure natural and forced convection, and then proceeded with mixed convection. The extremes of natural and forced convection were first tested so that a comparison could be made with previous results with spheres. In mixed convection, each object was tested for three different Grashof numbers. For the strawberry, the three Grashof numbers were nominally 85 000; 120 000; and 185 000. Other objects were tested under nominal Grashof numbers of 250 000; 500 000; and 900 000. Each group consisted of 8–12 data points. These data points were taken on two separate days and the results showed good reproducibility.

Experimental results were obtained through the following steps.

1. The total heat loss from the object to air was obtained from the measurement of the electrical power input.
2. The radiation heat loss from the object to the testing chamber wall was calculated using measured temperatures and radiation shape factors.
3. The radiation heat loss was subtracted from the total heat loss to obtain the convection heat loss.
4. Results were grouped in the forms of dimensionless numbers.

3. Results

Results for pure natural convection are shown in *Figs 2* and *3* and for pure forced convection in *Fig. 4*. Bold lines in the figures are the curves for Eqns (9) and (10). Experimental data points and curves show good agreement. Experimental results were

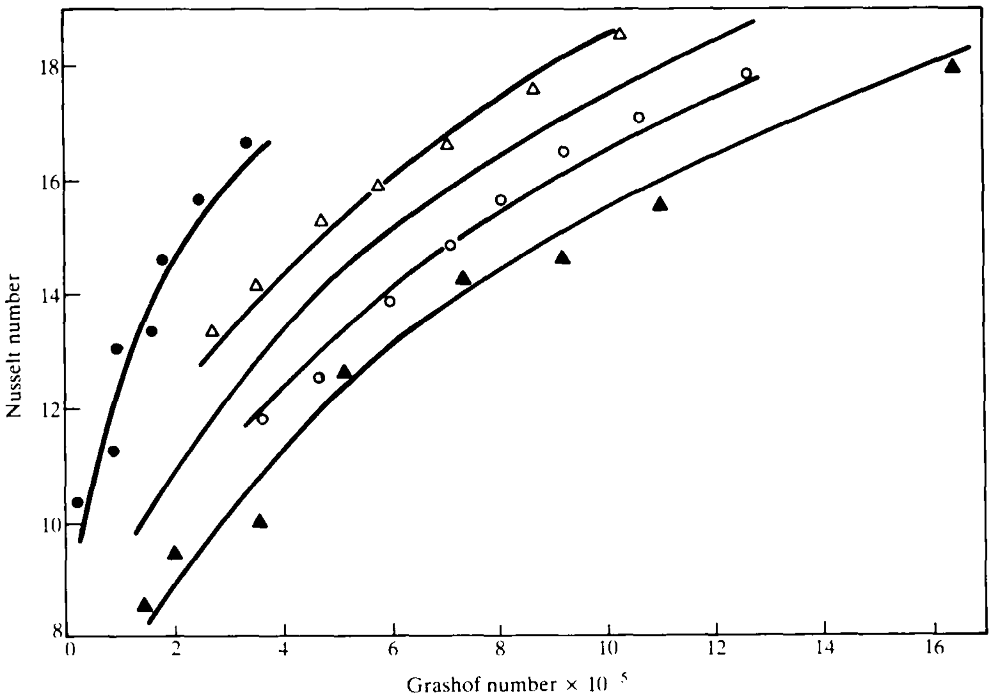

Fig. 2. Nusselt number versus Grashof number for natural convection. Lines through the points are calculated from Eqn (10). Data points correspond to strawberry (●), plum (△), peach (○), and apple (▲). The line for the sphere (centre) has no data points

compared with previous results from the study of the sphere.[3,4] Fruit and sphere exhibited the same general trend, but the curves were separated by constant offsets. Because of this, the general mathematical expressions used to calculate natural and forced convection for the sphere [Eqns (3) and (4)] were modified for use with fruits. Our results could be fitted by these equations with the addition of a constant in each of them. Eqn (9) is for pure forced convection and Eqn (10) is for pure natural convection.

$$\mathrm{Nu} = m\,\mathrm{Re}^{q} + A \tag{9}$$

$$\mathrm{Nu} = n\,\mathrm{Gr}^{p} + B \tag{10}$$

In Eqns (9) and (10), $m = 0{\cdot}673$, $n = 0{\cdot}336$, $q = 0{\cdot}515$, and $p = 0{\cdot}286$. These values were obtained from experimental observation of the sphere,[3,4] described previously. Values for the factors A and B were determined by plotting experimental results for the fruit shapes and comparing them to the sphere. Estimated values for A and B, which represent the differences between the sphere and the fruits, and also the differences among different fruit shapes, are shown in Table 1. Although the curve for the strawberry does not appear to be parallel to that of the sphere in *Fig. 2*, it can be seen from *Fig. 3* that the two curves are indeed parallel.

Differences in Nusselt number between the regular-shaped and smooth-surfaced sphere and the irregularly shaped and rougher-surfaced fruit models can be shown by considering the plum. The plum model is about the same size (0·057 m characteristic diameter) as the sphere (0·0575 m diameter), but the plum has a higher Nusselt number for both forced

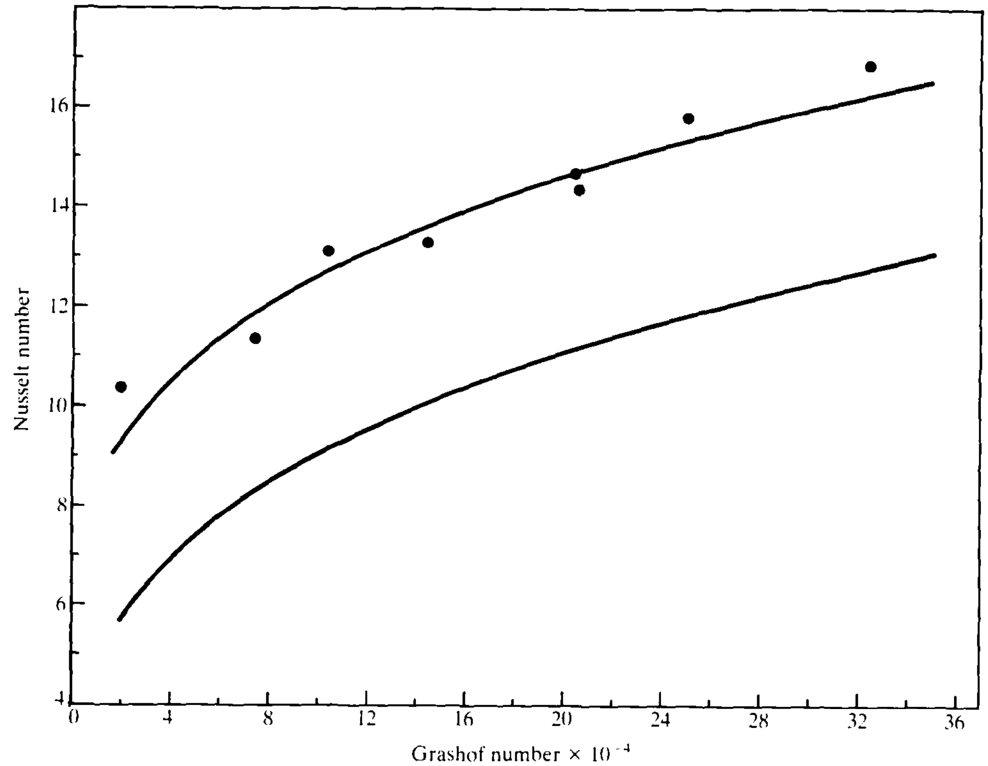

Fig. 3. Nusselt number versus Grashof number for natural convection from the strawberry. Although the strawberry line (●) does not appear to be parallel to the sphere line (without points) in Fig. 2, it clearly appears parallel when replotted on this expanded scale

and natural convection. This was probably due to the irregularity of the plum shape, which probably caused more turbulence and vortices along the surface.[9]

Among the fruit models, the larger-sized fruit exhibited smaller Nusselt numbers for both natural and forced convection. Typical surface temperature distributions in Tables 2 and 3 are the likely reasons for this.

The surface of the plum was divided into four segments (top windward, bottom windward, top leeward and bottom leeward) and surface thermocouples were attached to each segment. In the natural convection case, the temperature showed a tendency to be higher in the top segments and lower in the bottom segments. This indicates that the rising hot air accumulated around the top part of the model, which caused a smaller temperature difference between the air and surface (which is the driving force of natural convection(around the top part of the model. This resulted in lower natural convection from the top, and surface temperatures of that part increased. Comparing Tables 2 and 3, it can be seen that at nearly the same Grashof number, the peach had a larger temperature difference between the bottom and the top. Thus, the larger peach had a lower convection coefficient than the smaller plum.

In the case of forced flow, Tables 2 and 3 show that there was a significant temperature difference between the windward and leeward sides of the surface. This indicates that there was much smaller forced flow on the leeward side. This conclusion has also been shown by smoke flow patterns by Tang.[3,9] The larger object with the smaller surface

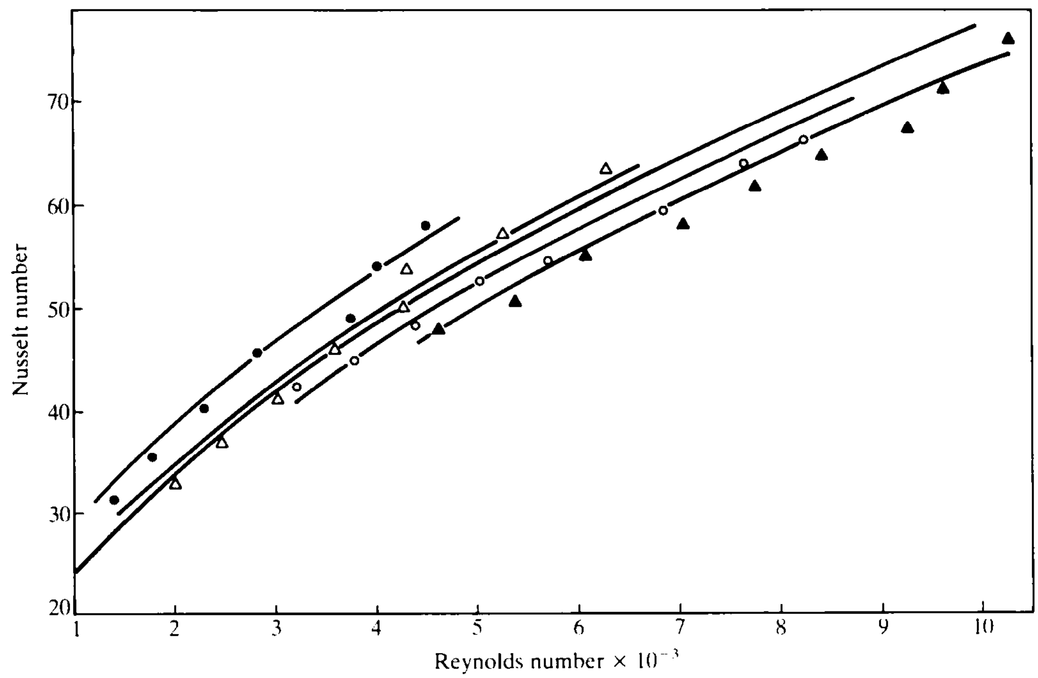

Fig. 4. Nusselt number versus Reynolds number for forced convection. Lines through the points are calculated from Eqn (9). Data points correspond to strawberry (●), plum (△), peach (○), and apple (▲). The line for the sphere is in the centre

Table 1
A and B values for different fruits

	Apple	*Peach*	*Plum*	*Strawberry*
A	−4	−2	1	5
B	−2	−1	1	3·5

Table 2
Typical surface temperature (°C) distribution for plum

	Top windward	*Bottom windward*	*Top leeward*	*Bottom leeward*
Natural	41·2	38·2	40·9	38·7
Forced	37·6	36·5	42·6	40·4

Natural convection data is at a Grashof number of 305 500.
Forced convection data is at a Grashof number of 385 200, and a Reynolds number of 6539.
Windward and leeward terms refer to forced flow.

Table 3
Typical surface temperature (°C) distribution for peach

	Top windward	*Bottom windward*	*Top leeward*	*Bottom leeward*
Natural	41·4	35·4	41·5	34·1
Forced	29·0	28·2	34·2	32·3

Natural convection data is at a Grashof number of 347 900.
Forced convection data is at a Grashof number of 310 100, and a Reynolds number of 5526.

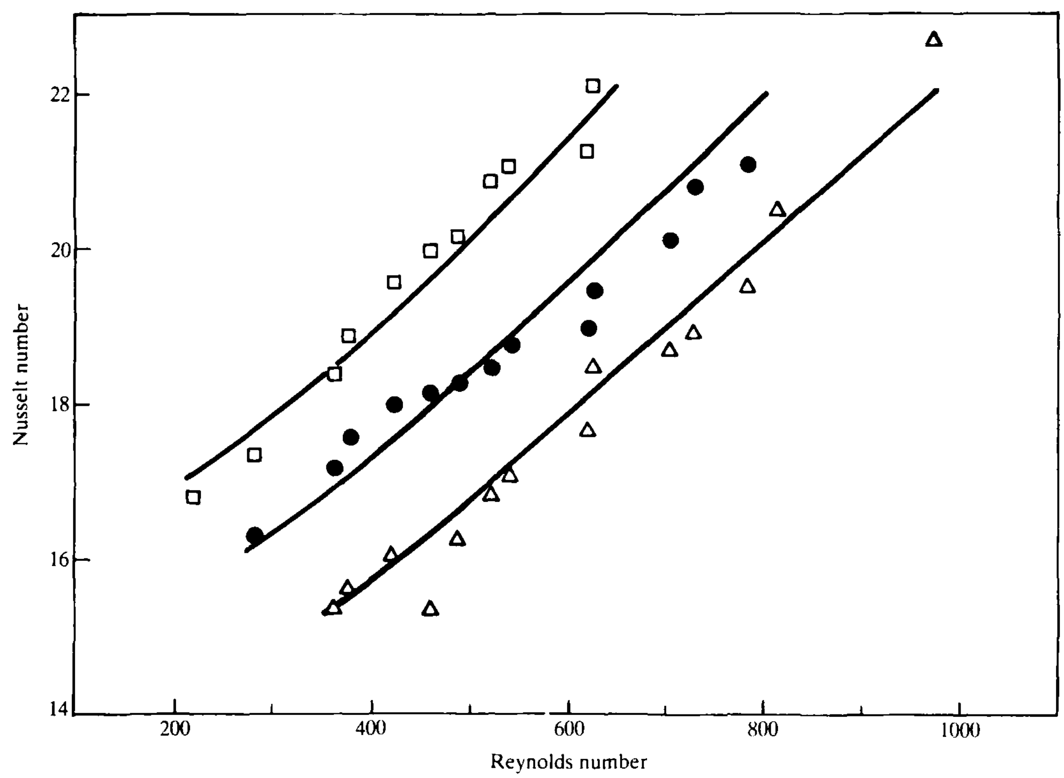

Fig. 5. Nusselt number versus actual Reynolds number for mixed convection at a Grashof number of 250 000. Lines through the points are calculated using methods described in the text. Data points correspond to plum (□), peach (●), and apple (△)

curvature blocked the leeward air flow more completely, leaving a larger portion of the leeward side untouched by the forced airflow. Thus the overall Nusselt number decreased.

Mixed convection Nusselt numbers were found to be calculable using the EDSA method as described previously. Since Eqns (3) and (4) were changed to Eqns (9) and (10), Eqn (5) now takes the form of:

$$Re_{eq} = [(n\ Gr^{*p} - A + B)/m]^{1/q} \tag{11}$$

With these modifications, the procedure for the EDSA method was found to give accurate results.

Fig. 5 shows some typical mixed convection curves for plum, peach and apple. Curves were obtained using the EDSA method with values of A and B appearing in Table 1. Points are actual measured data.

Since the characteristic diameter of the strawberry was significantly smaller than all the other objects, its Grashof number testing range was much lower than others, and its results could not be put onto the same graph with the others. However, even with Grashof number values between 85 000 and 180 000, which is much smaller than the Grashof values of 250 000 to 900 000 for the other objects, the Nusselt numbers for the strawberry are equal to or higher than those of the others. *Fig. 6* shows the mixed convection curves for the strawberry. Recall from the equipment section that the

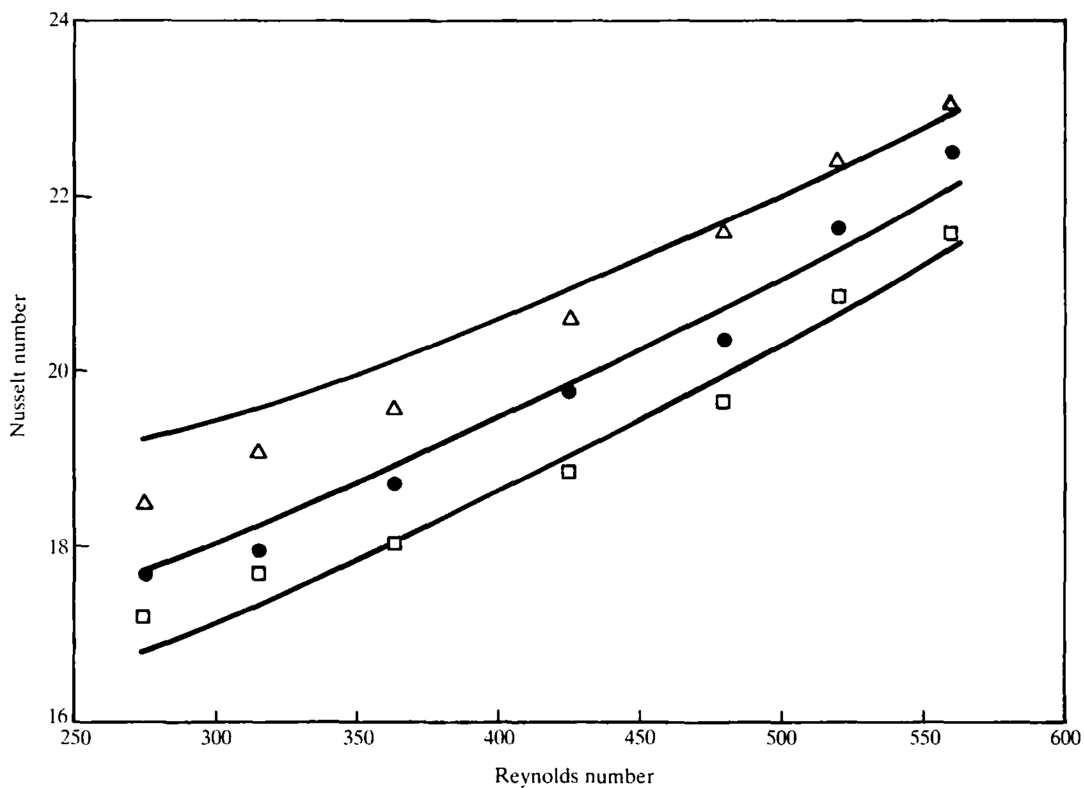

Fig. 6. Nusselt number versus actual Reynolds number for mixed convection for the strawberry. Lines through the points are calculated using methods described in the text. Data points correspond to Grashof number values of 85 000 (△), 110 000 (●), and 180 000 (□).

strawberry used in this experiment had the most irregular shape. This irregularity probably caused more turbulence and vortices, which then caused stronger heat transfer.

4. Discussion

We have provided not only convection data for several fruit shapes in wholly forced and natural flows, but also a means to combine the two to predict mixed convection. From this standpoint, this experiment and analysis of experimental results were successful.

However, several questions still remain. Surface temperature differences of several degrees were measured on our models (in some larger models, it even exceeded 10°C). What are the implications if this is the same for real fruit? These hot spots could be more subject to local spoilage than cooler spots. Also, higher Nusselt numbers were attributed to shape irregularities compared to the sphere. Are there other major factors that also influence the heat transfer rate?

Characterizing the sizes of these models caused great difficulty. Certainly, irregularity of shape was not easy to deal with. Orientation of the fruit with respect to the direction of airflow may significantly change the results.

Values for the constants A and B were determined by eye rather than by some other means. Perhaps those who would wish to use these values would like to make more precise estimates, and they may from data in the Appendix and from the equations for forced and natural convection from a sphere. However, added precision in the estimates for A and B does not guarantee added accuracy for future calculations. It is just as important that we know that equations for the sphere can be modified for fruits by adding or subtracting constant values as it is to know values of the constants. Given the variability of fruit shapes, our values for A and B are about as precise as they need to be.

It is interesting to speculate about a parallel between equations for convection from a sphere and those determined in this paper to apply to fruit. The equation to correlate spherical convection data is often given as:[10]

$$N = 2{\cdot}0 + m\,\mathrm{Re}^{q} \tag{12}$$

where the constant term is used to account for convection in totally still environments. Actually, heat is transferred by conduction in totally still environments, so the constant term does not appear where natural convection could arise.

Constants determined in this paper for the various fruits are not likely to have the same meaning as the 2·0 in Eqn (12). Our models were heated and so were free to develop natural convection instead of conduction. More likely, the constants in our equations are the result of vortex shedding and turbulence. If this is the case, one would not expect the distances between natural and forced convection curves to be constant as the condition of still air is approached.

Using a moulding compound with lower thermal conductivity than appears in real fruit would have had some affect on the experimental results, but exactly how much is not clear. Since convection is a surface phenomenon, and the shape of the fruit models is the same as the fruits themselves, measured convection coefficients should be basically correct, but with an indirect influence of the moulding compound. The lower thermal conductivity probably contributed to surface temperature non-uniformity, and this would influence overall convection coefficients. Nevertheless, the moulding compound thermal conductivity differs from the expected fruit thermal conductivity by only a factor of 2–3 and not by orders of magnitude. Therefore, some temperature non-uniformity would be expected to appear on the surface of real fruits, and convection coefficients for the fruits are probably not too different from those measured for the models.

The last item for discussion is the relation of this experiment and its results to practical situations. Fruit is not usually cooled singly and separated from other fruit. Thus, of what practical importance are the results from this experiment?

Our approach to the problem of mixed convection has been systematic: we first tested spheres with the idea that mixed convection Nusselt numbers should be determinable from equations related to pure forced and pure natural convection. The EDSA approach resulted from those experiments, and the importance of the EDSA method is that mixed convection Nusselt number can be determined for any combination of Reynolds and Grashof numbers without experiments designed to test specific combinations.

Results in this paper demonstrate the correctness of our approach. Without the experience with the sphere to draw from, a systematic approach to mixed convection Nusselt number from fruit-shaped objects would have been much more difficult to achieve. By comparing the fruits with the sphere, analogies become apparent, and we found that the EDSA method, slightly modified from the sphere, could work with fruits. Although there are fruit shapes we did not test, we can deduce that the forms of the pure natural and pure forced convection equations, and their combinations to mixed convection, will likely be similar to those determined in this experiment, with differences in the values of A and B to distinguish other shapes.

It does not take much imagination to realize that the next step in this process is to test packed fruits to see if mixed convection can be determined from pure forced and pure natural convection relationships. Therefore, the practical use of this experiment is the idea that results from ideal shapes can be extended to cover non-ideal shapes. Packed fruit represents another step away from the ideal.

5. Conclusions

Mixed convective Nusselt numbers for isolated fruit shapes can be predicted from convection equations for pure forced and natural convection. These equations are the same as those for a sphere with the addition of constant numbers.

References

[1] **Kirk, G. D.** Empirical analysis of mixed convective heat transfer from a sphere to air. Unpublished M.S. Thesis. 1984. University of Maryland, College Park, MD.

[2] **Kirk, G. D.; Johnson, A. T.** Empirical determination of mixed convective heat transfer from a sphere to air, International Communications in Heat Mass Transfer 1986, **13:** 369–387.

[3] **Tang, L.** Experimental investigation of mixed convection from a sphere to air. Unpublished M.S. Thesis. 1988. University of Maryland, College Park, MD.

[4] **Tang, L.; Johnson, A. T.; McCuen, R. H.** Empirical determination of mixed convection about a sphere, Journal of Agricultural Engineering Research 1991. (Submitted).

[5] **Peleg, M.; Bagley, E. B.** Physical Properties of Foods. Westport, CT: AVI Publishing Company 1983.

[6] **Mohsenin, N. N.** Physical Properties of Plant and Animal Materials. New York, NY: Gordon and Breach Science Publishers, 1970.

[7] **Daugherty, R. L.; Ingersoll, A.C.** 5th ed. Fluid mechanics with engineering applications. New York, NY: McGraw-Hill Book Company, 1954.

[8] **Sparrow, E. M.; Cess, R. D.** Radiation heat transfer New York, NY: McGraw-Hill Book Company, 1978.

[9] **Tang, L.; Johnson, A. T.** Flow visualization of mixed convection about a sphere. International Communications in Heat and Mass Transfer 1990, **17:** 67–77.

[10] **Yuge, T.** Experiments on Heat Transfer from Spheres Including Combined Natural and Forced Convection, Journal of Heat and Mass Transfer 1960, **82**(c): 214–220.

Appendix

Natural, forced, and mixed convection experimental data are difficult to obtain and are therefore rarely found. Since these data may be valuable for some readers, they are included in this appendix.

Table A1

Natural convection data

Fruit	*Grashof number*	*Nusselt number* *Observed*	*Predicted*
Strawberry	20 010	10·3	9·31
	75 050	11·3	11·8
	105 040	13·1	12·7
	145 100	13·2	13·6
	205 000	14·3	14·6
	251 030	15·7	15·3
	325 100	16·8	16·2
Plum	291 000	13·3	13·3
	259 000	14·3	14·0
	487 000	15·5	15·2
	598 000	16·2	16·1
	695 000	16·5	16·7
	841 000	17·3	17·6
	1 033 000	18·0	18·6
Peach	368 000	11·8	12·1
	477 000	12·8	13·1
	598 000	13·8	14·1
	704 000	14·8	14·8
	805 000	15·4	15·4
	947 000	16·4	16·2
	1 072 000	16·9	16·8
	1 251 000	17·9	17·6
Apple	151 000	8·58	8·17
	198 000	9·63	8·99
	348 000	9·95	10·9
	541 000	12·7	12·7
	743 000	14·2	14·0
	939 000	14·8	15·2
	1 173 000	15·9	16·3
	1 633 000	17·0	18·1

Predicted Nusselt number is 0·336 $Gr^{0.286} + B$, where $B = -2, -1, 1$, and 3·5 for apple, peach, plum, and strawberry shapes.

Table A2

Forced convection data

Fruit	*Reynolds number*	*Nusselt number* *Observed*	*Predicted*
Strawberry	1411	30·9	33·2
	1782	35·1	36·8
	2310	40·2	41·3
	2825	45·4	45·3
	3756	48·9	51·7
	4011	53·9	53·3
	4517	57·8	56·3
Plum	2028	32·9	35·0
	2477	36·9	38·7
	3032	41·0	42·8
	3610	46·1	46·7
	4287	50·0	51·0
	4330	53·6	51·2
	5291	57·2	56·7
	6316	63·8	62·0
Peach	3232	42·1	41·2
	3794	44·8	44·9
	4402	47·9	48·6
	5032	52·4	52·3
	5738	54·5	56·0
	6845	59·4	61·6
	7668	63·8	65·4
	8254	66·1	68·0
Apple	4641	48·0	48·0
	5398	50·5	52·2
	6113	55·0	56·0
	7065	58·0	60·6
	7789	61·7	63·9
	8471	64·5	66·9
	9322	67·0	70·5
	9661	71·2	71·9
	10 284	76·1	74·4

Predicted Nusselt number is 0·673 $Re^{0.515} + A$, where $A = -4, -2$ 1, and 5, for apple, peach, plum, and strawberry shapes.

Table A3
Mixed convection data

Fruit	*Reynolds number*	*Grashof number*	*Nusselt number observed*
Apple	563	251 000	15·35
	578	252 000	15·56
	624	249 000	15·98
	660	250 000	15·34
	689	251 000	16·23
	723	247 000	16·78
	743	248 000	17·06
	821	249 000	17·64
	828	250 000	18·45
	905	251 000	18·67
	930	252 000	18·89
	983	249 000	19·45
	1 015	250 000	20·45
	1 173	251 000	22·63
	245	514 000	15·67
	283	507 000	15·81
	335	502 300	16·34
	381	512 000	16·58
	430	523 000	16·99
	485	513 000	17·01
	535	508 000	17·34
	595	511 000	17·88
	659	515 000	18·12
	704	507 000	18·19
	243	912 000	17·89
	293	910 000	18·75
	348	909 000	18·54
	391	908 000	18·77
	442	909 000	19·43
	489	907 000	19·52
	545	912 000	19·88
	595	911 000	20·25
	644	910 000	20·43
	702	909 000	20·64
Peach	485	251 000	16·26
	565	250 000	17·14
	575	247 000	17·54
	624	249 000	17·95
	663	250 000	18·10
	692	251 000	18·23
	725	249 000	18·43
	747	248 000	18·73
	817	250 000	18·95
	830	254 000	19·43
	903	252 000	20·07
	934	250 000	20·74
	983	251 000	21·05
	263	513 000	16·99
	279	509 000	17·13
	323	515 000	17·53
	376	512 000	17·70
	423	510 000	17·88
	488	508 000	18·24
	532	509 000	18·47
	586	511 000	19·10
	634	512 000	19·56
	240	905 000	19·53
	288	904 000	19·67
	331	906 000	19·94

Table A3—(Contd.)

Fruit	*Reynolds number*	*Grashof number*	*Nusselt number observed*
Peach	382	904 000	20·44
	423	903 000	20·67
	479	902 000	20·54
	523	903 000	20·69
	583	904 000	20·97
	635	903 000	21·35
	688	904 000	21·66
Plum	420	254 000	16·79
	484	249 000	17·34
	565	250 000	18·35
	580	251 000	18·88
	628	251 000	19·57
	665	250 000	19·95
	691	249 000	20·13
	728	248 000	20·85
	745	250 000	21·04
	819	249 000	21·24
	831	250 000	22·05
	240	507 000	19·03
	285	508 000	19·34
	325	509 000	19·61
	375	509 000	20·14
	419	515 000	20·54
	478	503 000	20·88
	522	504 000	21·09
	576	505 000	21·23
	637	504 000	21·76
	688	505 000	21·93
	245	893 000	20·34
	289	901 000	20·89
	334	900 000	21·13
	389	898 000	21·99
	445	903 000	22·67
	499	904 000	23·06
	542	898 000	23·54
	599	902 000	24·01
	654	901 000	24·43
Strawberry	275	83 400	17·18
	315	83 800	17·68
	363	84 300	18·01
	425	84 800	18·85
	480	85 100	19·62
	520	85 200	20·84
	560	85 500	21·55
	277	107 000	17·65
	318	108 000	17·93
	362	110 000	18·69
	427	111 000	19·74
	483	109 000	20·32
	523	108 000	21·60
	562	110 000	22·47
	273	176 000	18·48
	312	178 000	19·07
	361	181 000	19·54
	423	180 000	20·56
	478	182 000	21·56
	517	179 000	22·35
	558	180 000	22·93