ENERGY EFFICIENCY ANALYSIS OF THE SEA BUCKTHORN (*HIPPOPHAE RHAMNOIDES*) FRUITS QUICK FREEZING

I. A. Korotkiy [a],*, E. V. Korotkaya[a], and V. V. Kireev[b]

[a] Kemerovo Institute of Food Science and Technology (University),
Stroiteley blvd. 47, Kemerovo, 650056 Russian Federation

[b] Tulunskiy myasnoy dvor LLC,
Myasokombinatskaya Str. 31, Tulun, 665268 Russian Federation

* e-mail: krot69@mail.ru

Received March 28, 2016; Accepted in revised form May 18, 2016; Published June 27, 2016

Abstract: Low temperature preservation of perishable produce is a widespread technology of it's long-term conservation, at the same time freezing of foods being an extremely power-consuming process. When developing low temperature preservation technology it is important to aim both at retaining high quality of frozen food and improving the energy efficiency of the processes. This article presents the results of research that explores the energy efficiency when freezing the sea buckthorn (*Hippophae rhamnoides*) fruits in a fluidized bed quick freezer. The study offers a method to calculate an amount of energy consumed in the freezing process of the sea buckthorn cultivars in an air-blast quick freezer. It also outlines geometrical and mass parameters of the cultivars. The study simultaneously demonstrates an air flow rates calculation for the sea buckthorn fruits fluidization to occur; defines the air circulation energy cost at a velocity necessary for fluidization to be accomplished at different air temperatures, and calculates the energy consumption to produce an artificial cold to ensure the required temperatures of heat transferring air. Further, the article conducts an analysis of the overall interconnected factors that impact the berries freezing energy consumption. Based on data obtained through research the authors reveal the energy efficient regimes of the sea buckthorn fruits low temperature treatment in an air-blast quick freezer; types of refrigerating machines and refrigerant that would ensure the less power consuming quick freezing of the sea buckthorn. The research used the species grown in Kemerovo region.

Keywords: Sea buckthorn, quick freezing, freezing technologies energy efficiency

DOI 10.21179/2308-4057-2016-1-110-120 *Foods and Raw Materials*, 2016, vol. 4, no. 1, pp. 110–120.

INTRODUCTION

Nowadays, vitamin and mineral deficiency has become one of the most common features in the modern individual diet [1]. Fruits and berries are the natural source of biologically active substances. Entering the human body the substances reveal their physiologically active properties. They have a substantial effect on metabolism and organism vital activity [2]. The sea buckthorn is known to be one of the most valuable vitamin rich plants in the flora of Russia. The sea buckthorn fruit accumulates a significant amount (up to 350 mg%) of carotenoids, up to 450 mg% of ascorbic acid, up to 165 mg% of vitamin E, up to 0.8 mg% of folic acid, and also vitamins B, F, and P. It contains up to 3.5% of sugars and 3.2% of organic acids, oils, flavones, sterols, minerals of iron, boron, manganese, etc. [3].

Freezing is considered to be one of the most efficient food preservation methods. Frozen fruits and berries can be stored for many months as the moisture transfers into a solid state. Low temperatures and crystallization of moisture contained in fruits and berries create unfavorable conditions for the biochemical processes to occur, and speed of the process decreases [4].

Formation of ice crystals accompanies the freezing of product that contains moisture and destroys the object's structure. Both mechanical and osmotic factors lead to the destruction. In the process of freezing, crystals form outside cells, increase in size, and thus, deform and rupture cell membranes. Besides, growth of ice crystals found in intercellular space causes cell moisture to diffuse though membrane, and cells dehydrate.

The intensity and nature of changes occurring in the product treated by the low temperature depend on the conditions and parameters of the process, and the quality characteristics of the object being treated. The intensification of heat removal increases the amount of crystallization clusters, which encourage the formation of microcrystalline structure. Moreover, the higher the intensiveness of heat transfer is, the smaller crystals in the frozen product are [5]. The conditions provided, crystalline structure will be more homogenous and ice crystals will form both inside intercellular space and inside the cells.

An increase in the quantity of heat removed during fruit freezing can be achieved either through temperature decrease in heat transfer medium or acceleration of its circulation. The first scenario is of an extensive nature and can be attained at the expense of temperature difference increase between object treated by low temperature and heat removal medium. In the second case, a change in the quantity of heat removed will be of an intensive nature and accomplished at the expense of heat transfer coefficient increase between refrigerated object and refrigerating medium [6].

Intensification of heat transfer during fruit and berry freezing causes growth in energy use in both scenarios. The real processes use the combined effect of the two above listed factors to intensify heat removal during fruits and berries freezing.

Energy component in the cost of final product prepared from fresh-frozen fruits and berries plays an important role in the development of low temperature processing technology. Hence, the relation between temperature and convection factors becomes an essential element in optimization of energy consumption during low temperature treatment of fruits and berries.

The objective of this paper is to determine the low temperature treatment regimes that would minimize the amount of energy used in production of the quick frozen sea buckthorn fruits.

OBJECTS AND METHODS OF STUDY

The sea buckthorn fruits were fast frozen in a quick freezer, which is a mechanism providing high air circulation velocity and temperatures required for the low temperature treatment processes.

Fruits mass and volumetric characteristics are necessary to determine parameters of air flow in the freezer. Characteristics of fruits used in research are shown in Table 1 for each cultivar.

Critical air flow velocity w'_{cr} (m/s) characterizes the onset of fluidization process [7].

$$w'_{cr} = \frac{v_{air}}{d_{eq}} \times \frac{Ar}{1400 + 5.22\sqrt{Ar}}, \qquad (1)$$

where d_{eq} is the product's equivalent diameter (m); v_v is the kinematic viscosity of air (m^2/s); Ar is the Arckimedes number.

$$Ar = \frac{g \cdot d_{eq} \cdot \rho_{pr}}{v_{air}^2 \cdot \rho_{air}}, \qquad (2)$$

where g is the gravitational acceleration (m/s^2); ρ_{pr}, ρ_{air} are the product and air densities respectively (kg/m^3).

Critical air velocity w''_{cr} (m/s) characterizes the velocity of air medium when fruits can be blown away [7].

$$w''_{cr} = \frac{v_{air}}{d_{eq}} \times \frac{Ar}{18 + 0.6 \cdot \sqrt{Ar}}. \qquad (3)$$

The sea buckthorn fruits freezing time was calculated from the equation of Plank [8]:

$$\tau_f = \frac{q_f \cdot \rho_{pr}}{t_{cryo} - t_{air}} \times \frac{d_{eq}}{6}\left(\frac{d_{eq}}{4\lambda_f} + \frac{1}{\alpha}\right), \qquad (4)$$

where α is the heat transfer coefficient (W/(m^2 K)); λ_f is the heat transfer value of the frozen fruits portion (W/(m K)); ρ_{pr} is the frozen sea buckthorn fruits density (kg/m^3); q_f is the heat of solidification (J/kg); t_{cryo} is the sea buckthorn fruits cryoscopic temperature (°C); t_{air} is the air temperature (°C).

Heat removal is determined by the air condition and air flow velocity depending on the product's geometrical parameters.

Heat transfer coefficient was calculated according to the formula [9]:

$$\alpha = Nu \cdot \lambda_{air} / d_{eq}, \qquad (5)$$

where λ_{air} is the air thermal conductivity; Nu is the Nusselt number.

During the fluidization we use the following empirical equation to determine Nusselt number [10]:

$$Nu = 0.03 \cdot Pr^{1/3} \cdot Re, \qquad (6)$$

where $Pr = c_{air} \cdot \mu_{air} / \lambda_{air}$ is the Prandtl number; μ_{air}, c_{air} are the air dynamic viscosity and specific heat respectively; $Re = \omega \cdot d_{eq} \cdot \rho_{air} / \mu_{air}$ is the Reynolds number; ω, ρ_{air} are the air velocity and air density respectively.

The air mass m_{air} (kg) and air volume V_{air} (m^3) required to freeze 1kg of the sea buckthorn fruits are determined from the formulas:

$$m_{air} = \frac{\Delta h}{c_{air} \cdot \Delta t_{air}}, \qquad (7)$$

where Δh is the difference between the fruits enthalpies before and after freezing (J);

$$V_{air} = m_{air} / \rho_{air}. \qquad (8)$$

Quantity of heat removed from fruits Δh equals the quantity of heat transferred to air Δh_a in refrigerated volume.

Air heating Δt_{air} during the sea buckthorn fruits freezing determined according to the formula:

$$\Delta t_{air} = \alpha \cdot F_{pr} \cdot \Delta t_t, \qquad (9)$$

where F_{pr} is the sea buckthorn fruits surface area (m^2); Δt_t is the logarithmic mean difference between air temperature and the temperature of the sea buckthorn fruits being frozen (°C):

$$\Delta t_t = \frac{t_{air2} - t_{air1}}{\ln \dfrac{t_{cryo} - t_{air1}}{t_{cryo} - t_{air2}}}, \qquad (10)$$

here t_{air1} is the initial air temperature; t_{air2} is the final air temperature, $\Delta t_{air} = t_{air2} - t_{air1}$.

The following formula determines consumption of energy (L_a, J) necessary to reach the required air circulation velocity:

$$L_a = V_{air} \cdot \Delta P / \eta_f, \qquad (11)$$

where η_f is the fans performance factor; ΔP is the aerodynamic resistance of quick freezer (Pa) [7].

$$\Delta P_f = 1.67\left(\mathrm{Re}\frac{H_f}{d_{eq}}\right)^{0.2} \times \frac{G_{pr}}{F_{pr}}, \qquad (12)$$

where H_f is the fluidized bed depth (m); G_{pr} is the mass; F_{pr} is the fluidized bed depth flow area of the product (m^2).

$$H_f = H_0\left(\frac{1-\varepsilon_0}{1-\varepsilon}\right), \tag{13}$$

where H_0, ε_0 is the depth and porosity of the bed; $\varepsilon = \left(\frac{18\,\mathrm{Re} + 0.36\,\mathrm{Re}^2}{Ar}\right)^{0.21}$ is the porosity of the fluidized bed.

The aerodynamic resistance of the tray (ΔP_g):

$$\Delta P_g = 13.72 \cdot w^2 - 43.12 \cdot w + 119.36, \tag{14}$$

where w is the air flow velocity.

Aerodynamic resistance of air cooling agents (ΔP_{ac}) was calculated according to the formula:

$$\Delta P_{ac} = 1.35 \cdot A \cdot \mathrm{Re}^{-0.24} \rho_{air} \cdot w^2, \tag{15}$$

where A is the coefficient to account for the form factors.

Aerodynamic resistance to air flow in the circuit of quick freezer:

$$\Delta P = (\Delta P_f + \Delta P_g + \Delta P_{ac})\alpha, \tag{16}$$

where $\alpha = 1.1$ is the air friction coefficient.

Working substance of the refrigerating machine removes heat from the low temperature treated object and transfers it towards the surrounding environment. This substance largely determines refrigerating system efficiency [11].

The research studied the efficiency of artificial cold production in one-, two-stage, and cascade refrigerating machines, their operation based on Freons R-134a, R-22, R-404a, R-23, R-717. Energy consumption was measured in accordance with the work [12].

RESULTS AND DISCUSSION

Based on the experimental data shown in Table 1 and formulas 1÷3 we obtained values of critical velocities of the studied fruits. Fig. 1 displays the results of the calculations.

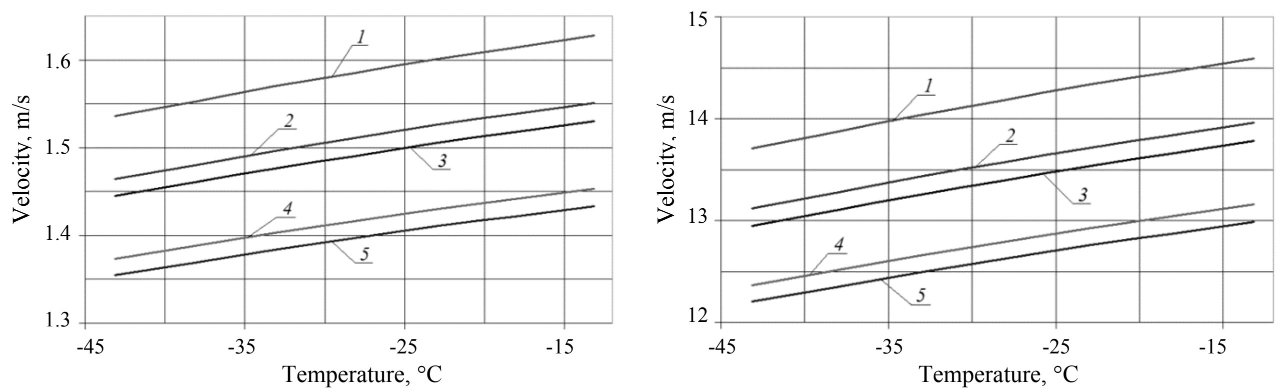
Drawing from the calculations, velocities that allow stable fluidization process to occur, range from 1.8 to 12 m/s. The velocity regime holds for the air temperature -43÷-13°C.

In accordance with formulas 4÷6 the sea buckthorn fruits freezing time was determined in relation to the air velocity and temperature. Fig. 2 displays the results of the calculations.

From formulas 7÷16 we found energy inputs required to circulate the air in quick freezer at variable velocities and temperatures. Energy consumption during the sea buckthorn fruits freezing determined from initial temperature t_i = 10°C to t_f = -18°C. The results are represented in Fig. 3.

Table 1. Mass and geometrical characteristics of the fruits by cultivars used in the research

Sea buckthorn cultivar	Diameter of a single product, mm	Mass of a single product	Product density, kg/m^3	Bulk density, kg/m^3	Bed porosity
Chuyskaya	10/12	0.6	943	662	0.301
Panteleevskaya	10/15	0.8	968	679	0.315
Dar Katuni	9/12	0.6	957	672	0.309
Maslyanichnaya	9/11	0.4	932	654	0.311
Zolotoy pochatok	11/11	0.7	960	674	0.310



(a) (b)

Fig. 1. Critical fluidization velocities dependence for the sea buckthorn fruits:
1 – "Zolotoy pochatok"; *2* – "Panteleevskaya"; *3* – "Chuyskaya"; *4* – "Dar Katuni; *5* – "Maslyanichnaya"
(a) initial fluidization velocity; (b) final fluidization velocity.

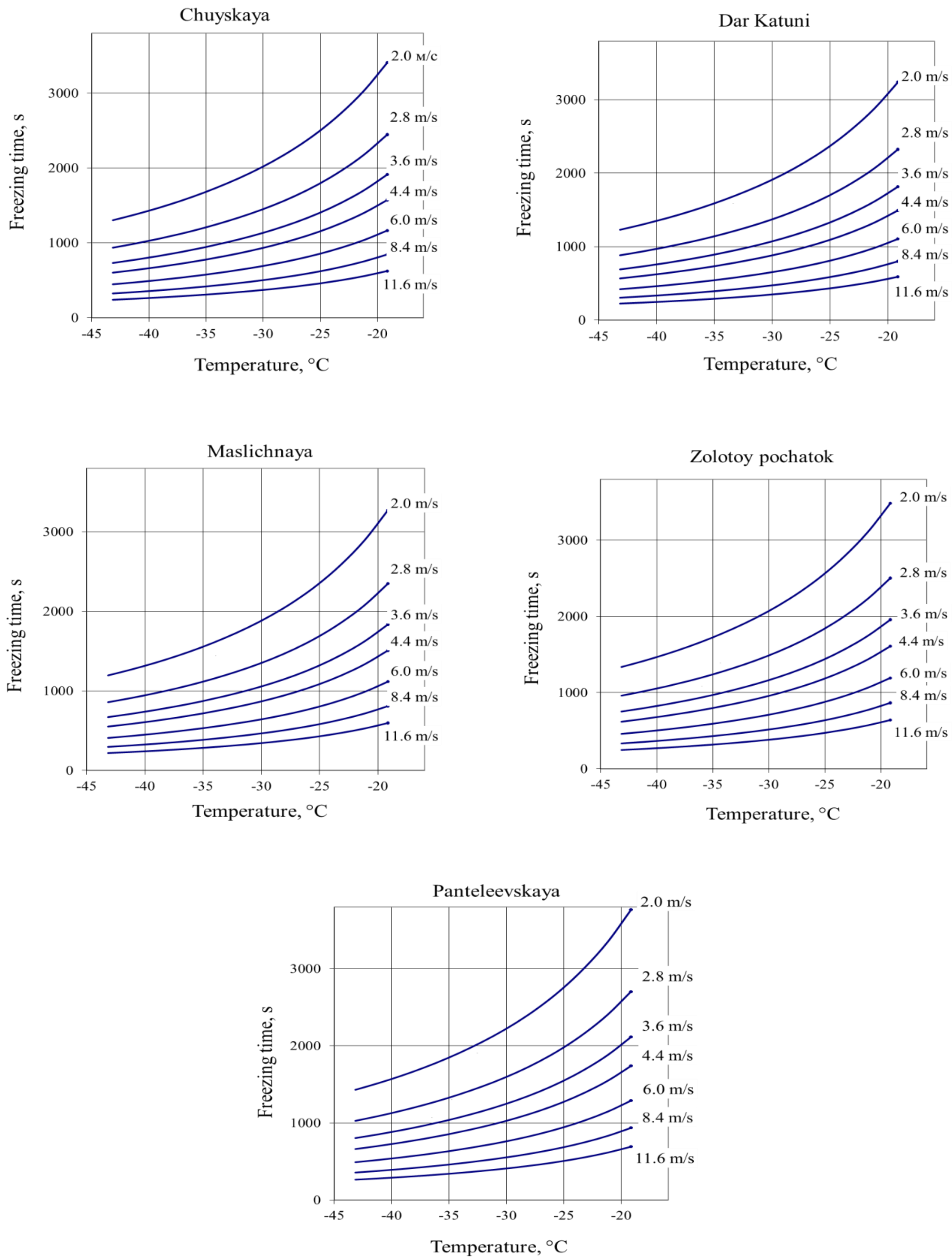


Fig. 2. The sea buckthorn fruits freezing time in relation to the temperature of air medium and fluidization velocity.

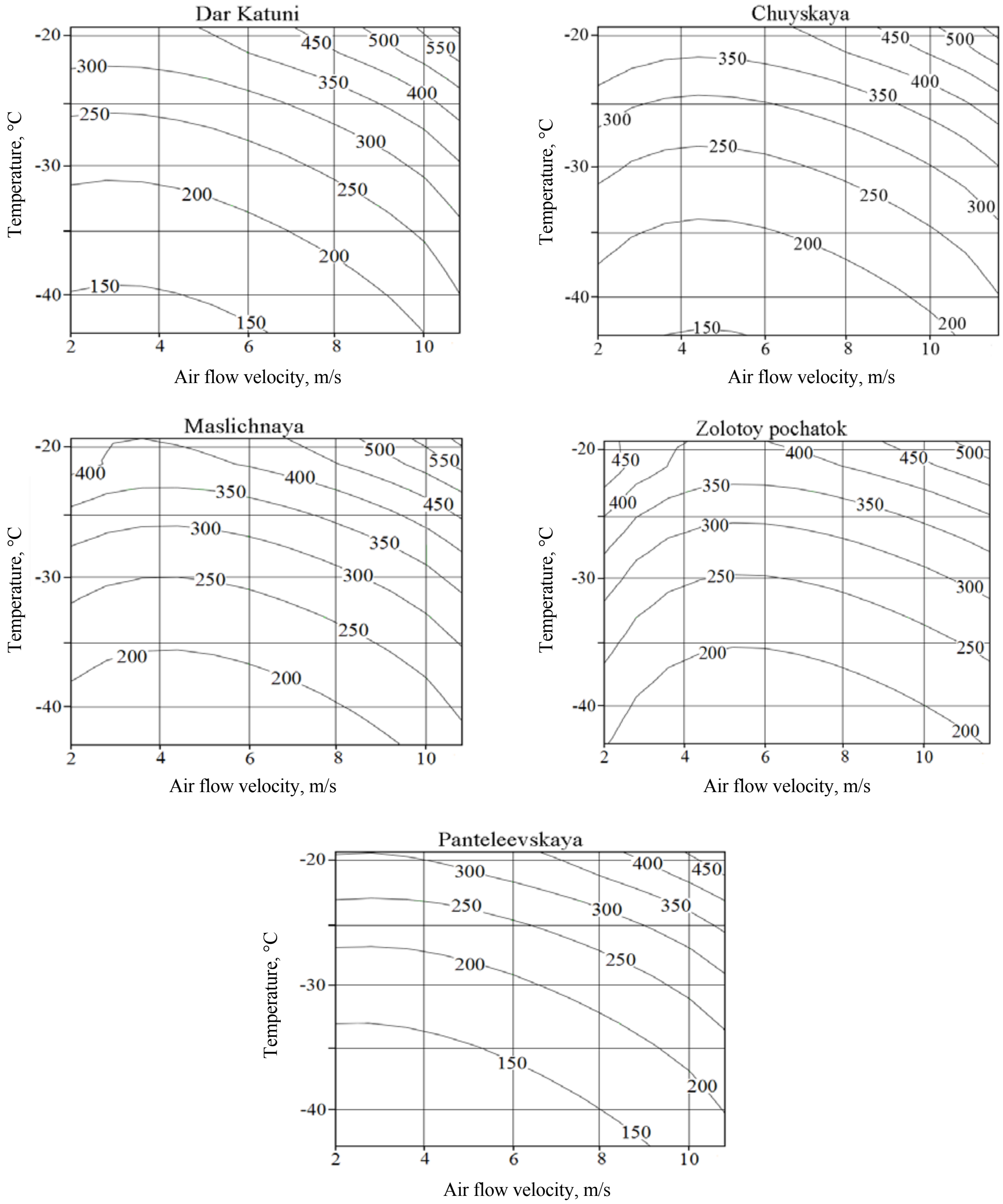


Fig. 3. Energy consumption (kJ/kg) to provide air flow in quick freezing machine to freeze 1kg of the sea buckthorn fruits in relation to air velocity and temperature.

The sea buckthorn fruits have quite a significant variability of air flow optimal velocity where energy consumption for its circulation is minimal. The optimal air velocity in the sea buckthorn freezing depends on the fruit cultivars. The fruit has oblong shape. During the freezing of the sea buckthorn cultivar "Zolotoy pochatok", its fruits having the least oblong shape, the optimal velocity regime for fluidization range from 5 to 6 m/s. And to freeze the sea buckthorn cultivar "Panteleevskaya", the fruits having the most oblong shape, the optimal fluidization regime is a velocity of approximately 2 m/s.

An increase in fluidization speed improves heat transfer from the fruits being frozen and hence, reduces the time of low temperature treatment and lowers consumption of air needed to remove the heat from freezing process. At the same time as the air flow velocity increases in quick freezer, the aerodynamic losses rise proportionally to the square of velocity. Thus, in the initial stage, an increase in air flow velocity leads to the reduction of energy consumed during product freezing. It occurs because energy used for reduction related to the decrease in amount of air consumed for freezing is more intensive than energy input growth, necessary to overcome aerodynamic resistances. Provided air velocity in quick freezer increases further, energy consumption growth necessary to overcome dynamic resistance takes the lead over the reduced amount of energy related to the decrease in the required amount of circulating air; therefore, total energy consumption for providing for air circulation grows.

Refrigeration capacity required to freeze 1 kg of the sea buckthorn fruits is calculated in relation to the air temperature in quick freezer and the temperature of surrounding air and is shown in Fig. 4.

The results outlined in Fig. 4 show that the Refrigeration capacity required to freeze the fruits of different cultivars varies insignificantly – not more than 1.9%.

For comparative energy efficiency analysis of the different refrigerating circuits we studied the cultivar “Zolotoy pochatok”.

Fig. 5 shows the results obtained through the comparative analysis of energy inputs to freeze the sea buckthorn fruits in single-stage compression refrigerating machine.

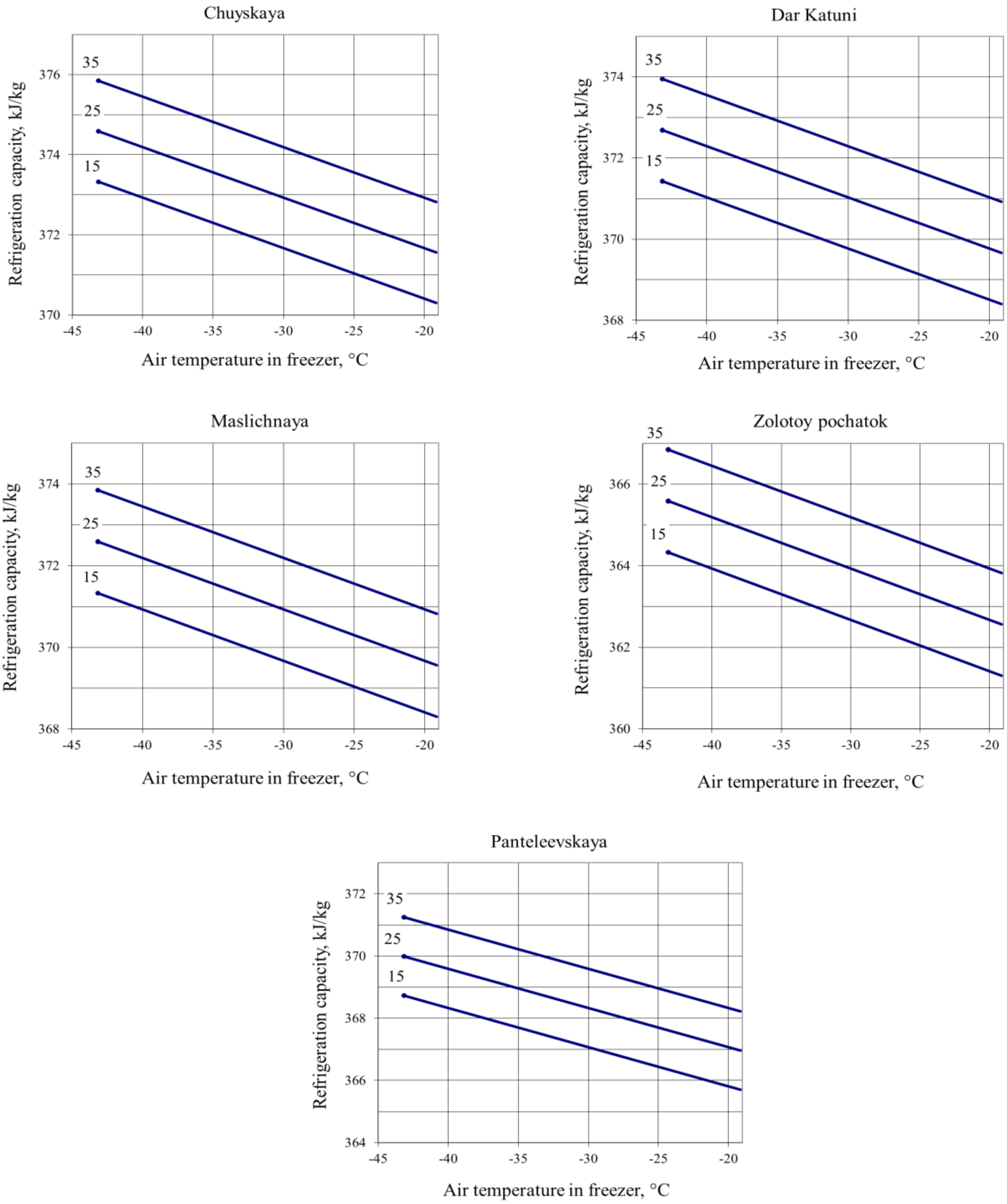


Fig. 4. Refrigeration capacity required to freeze 1 kg of the sea buckthorn fruits at temperature from 10°C to -18°C in relation to the temperatures of surrounding air and the air in quick freezy; 15°C, 25°C, 35°C are the temperatures of surrounding environment.

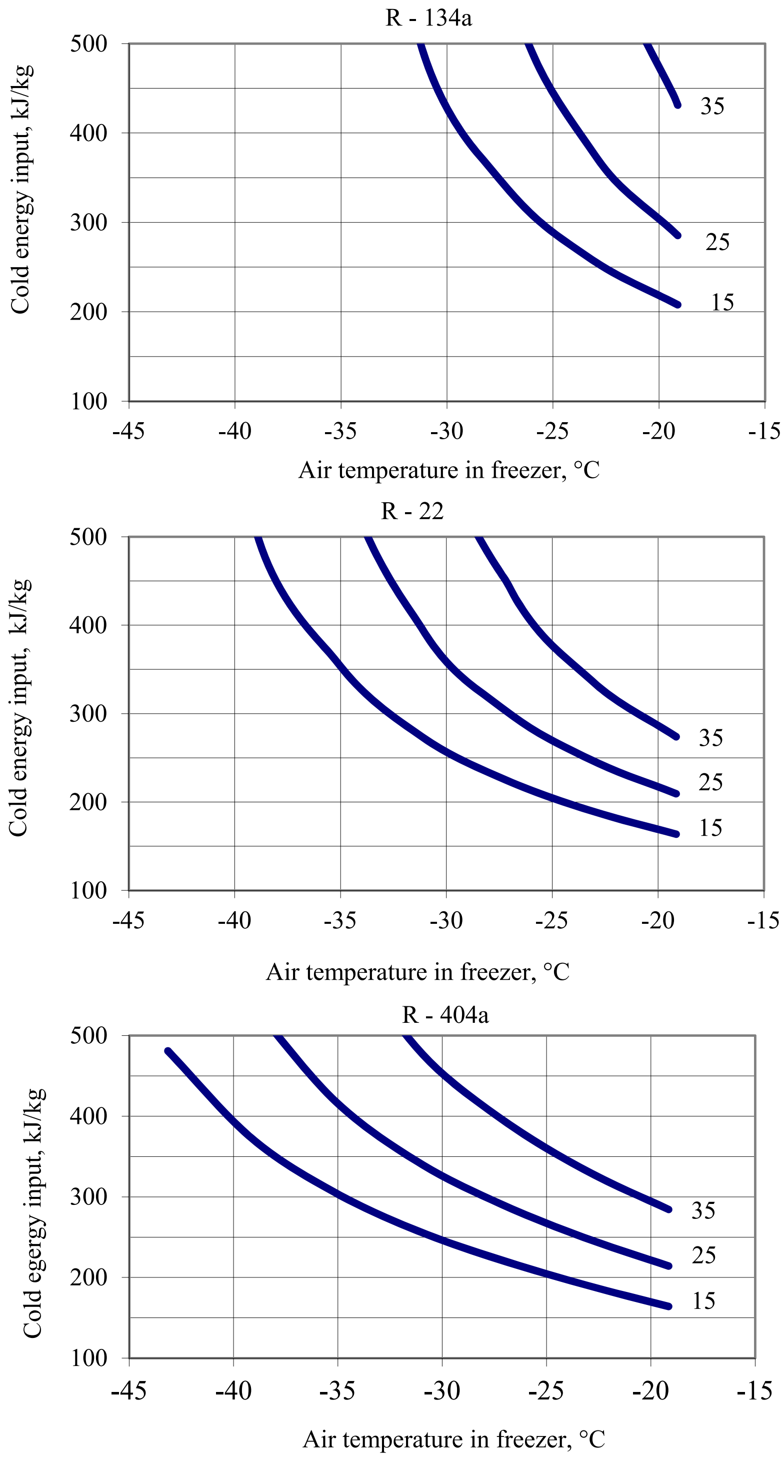


Fig. 5. Energy inputs to freeze 1 kg of the sea buckthorn fruits in single-stage refrigerating machine.

It is not desirable to use Freon R-134a in single-stage refrigerating machine because of excessive energy consumption.

Values of energy consumed to produce artificial cold with cooling unit temperature up to -25°C in single-stage refrigerating machines working on R-22 and R-404a are close. Further decrease of air temperature in quick freezer leads to a sharp rise in energy consumption for the refrigerating machine working on K-22. Single-stage refrigerating machine working on Freon R-404a can be used to attain -30°C temperature levels in quick freezer.

Fig. 6 shows the results of the energy efficiency analysis in relation to air temperatures in quick freezer and surrounding environment air when two-stage compression refrigerating machines used to freeze the sea buckthorn fruits.

Drawing upon the obtained results, application of Freon R-134a is not desirable for quick freezing in two-stage refrigerating machines either. Energy inputs are significantly higher compared to other refrigerants.

Energy efficiency of the refrigerating machines that use R-717 и R-22 as refrigerants, are approximately similar. Two-stage ammonia refrigerating machine has insignificant advantage over two-stage refrigerating machine that works on R-22 within temperature range up to -35°C. Having said that, the latter is more efficient than ammonia refrigerating machine at the temperatures lower than -35° C. However, Freon based refrigerating machine has better performance and costs less in comparison with ammonia refrigerating machine. Hence, it appears to be more efficient to utilize refrigerating machines using R-22 than ammonia-based.

Energy efficiency rates of the R-404a two-stage refrigerating machine are lower than those of the refrigerating machines working on R-22 и R-717.

Calculations for the energy consumed by cascade refrigerating machines to produce cold for quick freezers are shown in Fig. 7.

From the all studied cold producing circuits the cascade refrigerating machines perform best in terms of energy efficiency. However, practical application of the scheme is more complex.

With the volume refrigerated to attain temperatures ranging to -30°C the amount of energy used by cascade and two-stage refrigerating machines working on R-22, vary insignificantly. Freezing and operational performance of two-stage refrigerating machines being more straightforward and reliable, their application (with R-22) is advisable to the temperature values of -30°C. To reach temperature levels lower than -30°C the cascade refrigerating machines should be preferred.

Our study revealed that the highest energy efficiency of quick freezing processes can be achieved with optimal air velocity value that relate to geometrical and thermophysical parameters of the objects being treated by low temperatures. Change in the velocity of air medium in quick freezers, both and increase and decrease of the optimal values, causes energy cost of the low temperature treatment process to rise.

The lower the air temperature in quick freezer is, the higher heat transfer efficiency is. At the same time, it is accompanied by growth in energy consumption towards refrigerating machine drive. Fig. 8 shows the impact of the combined actions of these two factors on energy inputs required to freeze the sea buckthorn fruits.

Tables 2 and 3 offer the most efficient sea buckthorn fruits freezing regimes, the cold supplied by cascade and two-stage refrigerating machines.

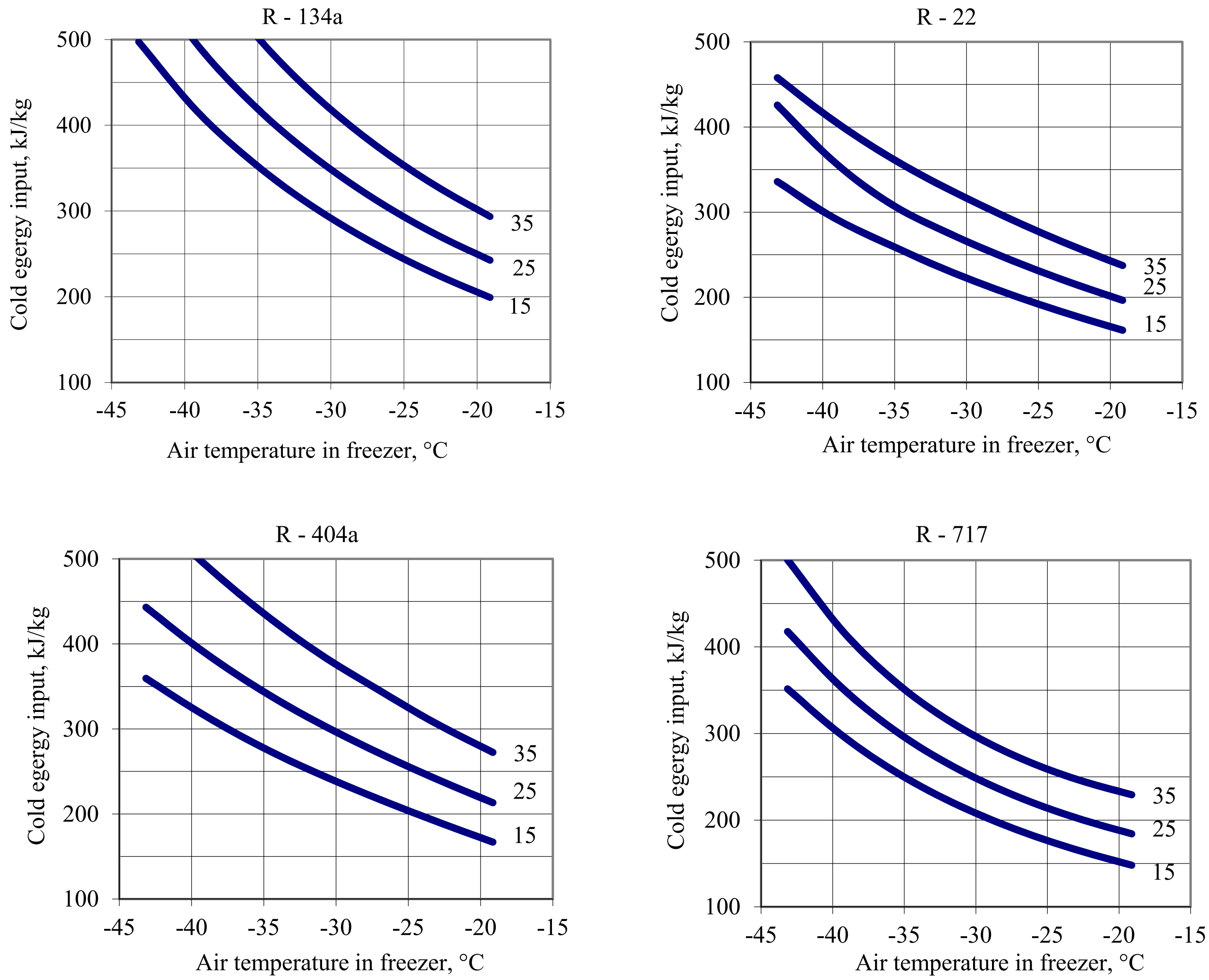


Fig. 6. Energy consumed to freeze 1 kg of the sea buckthorn fruits in two-stage refrigeration machine in relation to the temperatures of air in quick freezing unit and surrounding environment.

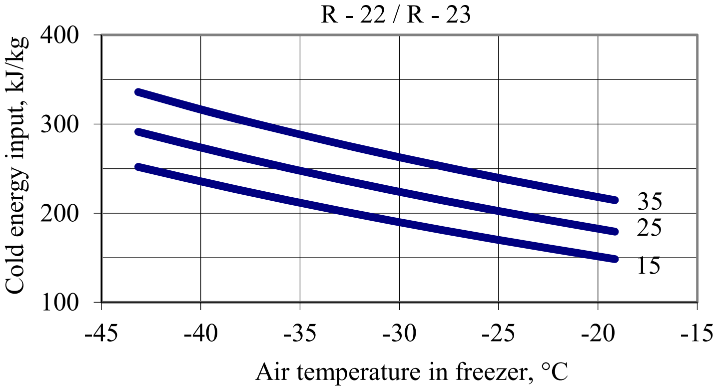


Fig. 7. Energy consumed to freeze 1kg of the sea buckthorn fruits in cascade refrigerating machine working on Freon R-23 in the lower branch and R-22 in the upper branch of cascade for variable air temperatures in quick freezer and of surrounding environment.

Table 2. Optimal freezing regimes (energy efficiency) for the fruits studied in quick freezing unit of cascade refrigeration machine

Sea buckthorn cultivar	Temperature of surrounding air, °C											
	15	25	30	15	25	35	15	25	35	15	25	35
	Air temperature in the machine, °C			Air flow velocity, m/s			Energy consumption (kJ) per freezing of 1kg of berries			Freezing time, s		
Chuyskaya	-39	-39	-39	4.4	4.4	4.4	410.1	449.4	493.6	678.9	678.9	678.9
Panteleevskaya	-35	-35	-35	2.8	2.8	2.8	358.3	395.5	437.8	1321.6	1321.6	1321.6
Dar Katuni	-39	-39	-39	2.8	2.8	2.8	392.4	431.5	475.5	995.9	995.9	995.9
Maslyanichnaya	-39	-39	-39	4.4	4.4	4.4	418.4	457.5	501.5	624.4	624.4	624.4
Zolotoy pochatok	-39	-39	-39	5.2	5.2	5.2	412.8	451.2	494.3	593.2	593.2	593.2

Table 3. Optimal freezing regimes (energy efficiency) for the fruits studied in quick freezing unit of two-stage refrigeration machine

Sea buckthorn cultivar	Temperature of surrounding air, ° C											
	15	25	30	15	25	35	15	25	35	15	25	35
	Energy cost per unit during freezing (kJ/kg)			Freezing time, s			Air velocity, m/s			Air temperature, °C		
Chuyskaya	464.9	511.3	565.1	893.5	893.5	893.5	4.4	4.4	4.4	-31	-31	-31
Panteleevskaya	401.4	447.2	500.4	1527.8	1527.8	1527.8	2.8	2.8	2.8	-31	-31	-31
Dar Katuni	440.3	486.5	540.0	1313.2	1313.2	1313.2	2.8	2.8	2.8	-31	-31	-31
Maslyanichnaya	475.3	524.4	578.0	714.6	829.8	829.8	4.4	4.4	4.4	-35	-31	-31
Zolotoy pochatok	471.6	516.9	569.4	780.0	780.0	780.0	5.2	5.2	5.2	-31	-31	-31

Optimal sea buckthorn fruits freezing regimes greatly vary depending on the cultivars. Presumably, this can be explained with the significant differences in geometrical parameters of fruits harvested from different cultivars.

The least energy consuming regime for cascade refrigerating machine appears to be freezers air temperature of -39°C, and for two-stage refrigerating machine it appears to be -31°C. The optimal air flow velocity in quick freezer ranges from 2.8 m/s for the fruits of cultivars "Dar Katuni" and "Panteleevskaya" to 5.2 m/s for the fruits of cultivars "Zolotoy pochatok". The smaller air flow velocities correspond to the fruits with more oblong shape. The sea buckthorn fruits freezing times in the most energy efficient regime at the temperature of -39°C were determined to range from 22 minutes for the cultivar "Panteleevskaya" and 17 minutes for the cultivar "Dar Katuni" to 10 minutes for the cultivar "Zolotoy pochatok". At temperature of -31°C the freezing time will vary from 25 and 22 minutes ("Panteleevskaya" and "Dar Katuni" respectively) to 12 minutes for the cultivar "Zolotoy pochatok". On average, in terms of energy efficiency the use of cascade refrigerating machine for the sea buckthorn fruits freezing is 13.8% more productive when compared with two-stage refrigerating machines.

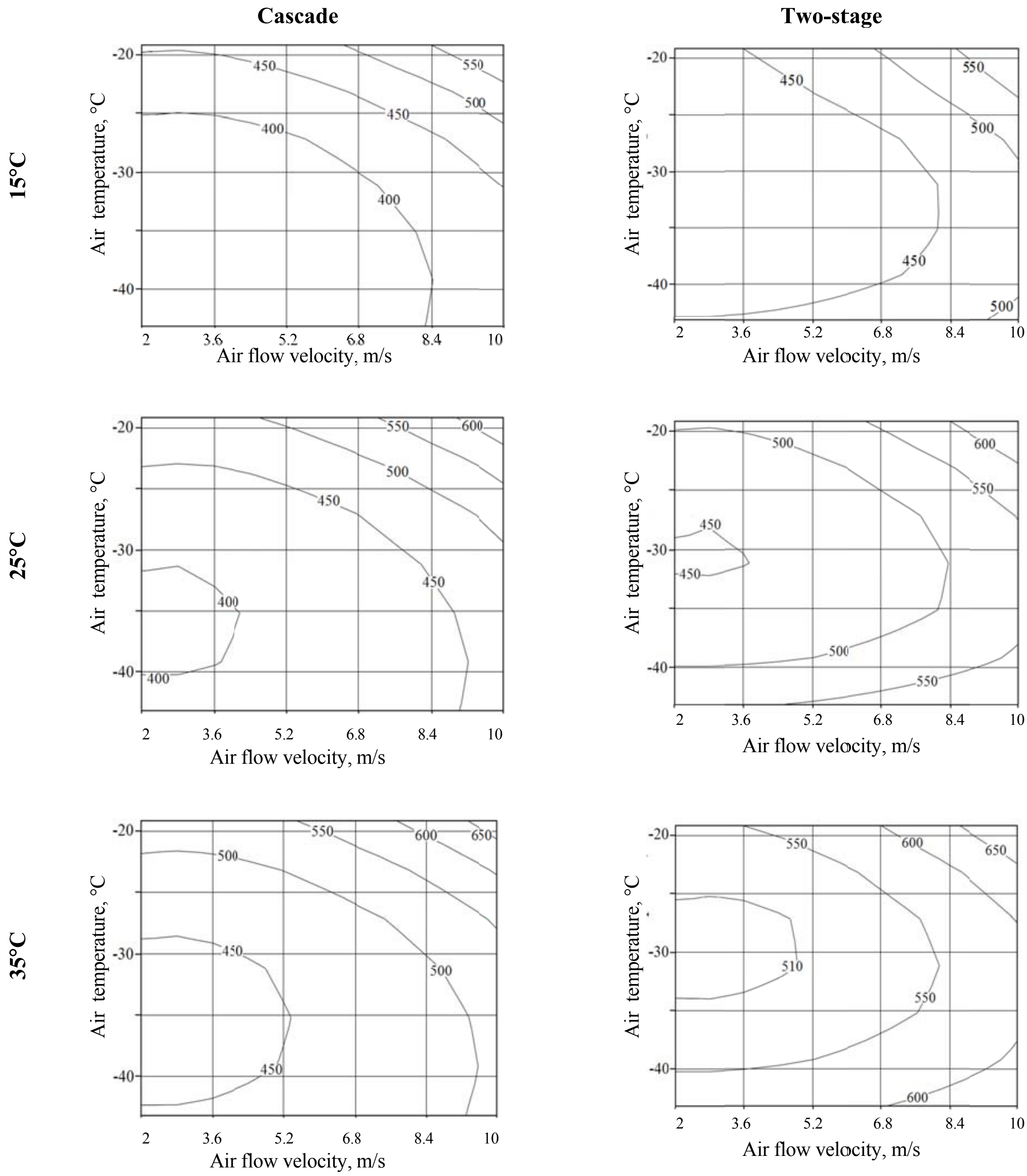


Fig. 8. Energy cost per unit (kJ/kg) in the process of freezing the sea buckthorn fruits of the cultivar "Panteleevskaya" in quick freezer receiving cold from cascade (R-23/R-22) and two-stage (R-22) refrigerating machines.

CONCLUSION

Thus, the performed calculations and analysis of the obtained data demonstrate that the use of cascade refrigerating machine for the sea buckthorn fruits quick freezing is significantly more energy efficient in comparison with other types of refrigerating machines. Moreover, sea buckthorn fruits quick freezing in the freezers that receive cold from cascade machines occurs under lower temperatures, which significantly accelerates low temperature treatment process and hence, improves the quality properties of the frozen fruit.

Cascade refrigerating machines has a higher price tag than two-stage machines. Their assembly and maintenance costs more, it requires more qualified staff to service them. However, increase in the equipment productivity due to the freezing time reduction and lower energy inputs to their drive in cascade refrigerating machines makes them more attractive economically for quick freezing of fruits and berries.

REFERENCES

1. Institute of Medicine (US) *Dietary reference intakes. Applications in dietary assessment*. Washington, D.C.: National Academies Press, 2000. 285 p.
2. Kalia R.K., Singh R., Rai M.K., Mishra G.P., Singh S.R., and Dhawan A.K. Biotechnological interventions in sea buckthorn (*Hippophae L.*): current status and future prospects. *Trees,* 2011, vol. 25, no. 4, pp. 559–575.
3. Prosekov A.Yu. Razrabotka metodiki opredeleniya kachestva plodovo-yagodnogo syr'ya. [Method development for fresh fruits and berries quality controls. Innovative technologies in the food industry]. *Materialy IX Mezhdunarodnoy nauchno-prakticheskoy konferentsii "Innovatsionnye tekhnologii v pishchevoy promyshlennosti" (7-8 oktyabrya 2010g.)* [Proc.of the 9th International scientific and practical conference "Innovative technologies in the food industry" (October 7 – October 8)]. Minsk, 2010, pp. 289–290.
4. Rahman Sh. (ed.) *Handbook of Food Preservation*. CRC Press, 2007. 1088 p.
5. Almási E., Erdélyi L., and Sáray T. *Élelmiszerek gyorsfagyasztása*. Budapest: Mezőgazdasági Kiadó, 1977. 367 p. (In Hungarian).
6. Rasshchepkin A.N., Korotkiy I.A., and Korotkaya E.V Vliyanie rezhimov nizkotemperaturnoy obrabotki na kachestvennye pokazateli yagod chernoy smorodiny [Effect of low-temperature processing on blackcurrants quality factors]. *Food Processing: Techniques and Technology*, 2014, no.1, pp. 101–105.
7. Golyand M.M., Malevannyy B.N., Pechatnikov M.Z., and Plotnikov V.T. *Sbornik primerov raschetov i laboratornykh rabot po kursu "Kholodil'noy tekhnologicheskoe oborudovanie"* [Collection of calculation examples and laboratory studies in "Commercial refrigeration equipment" course]. Moscow: Legkaya i pishchevaya promyshlennost' Publ., 1981. 168 p.
8. Baranenko A.V., Kutsakova V.E., Borzenko E.I., and Frolov S.V. *Primery i zadachi po kholodil'noy tekhnologii pishchevykh produktov. Ch.3 Teplofizicheskie osnovy* [Examples and assignments in Food products refrigeration technology. Vol. 3. Thermal Physics basics]. Moscow: Kolos Publ., 2004. 249 p.
9. Lykov A.V. *Teoriya teploprovodnosti* [Theory of the conduction of heat]. Moscow: Higher school Publ., 1967. 600 p.
10. Rogov I.A., Kutsakova V.E., Filippov V.I., and Frolov S.V. *Konservirovanie pishchevykh produktov kholodom* [Food preservation by cold]. Moscow: Kolos Publ., 1999, 176 p.
11 Baranenko A.V., Bukharin N.N., Pekarev V.I., Sakun I.A., and Timofeevskiy L.S. *Kholodil'nye mashiny* [Refrigeration machinery]. St. Petersburg: Politekhnika Publ., 1997, 992 p.
12 Korotkiy I.A. Analysis of the energy efficiency of the fast freezing of blackcurrant berries. *Foods and Raw Materials*, 2014, vol. 2, no. 2. pp. 3–15. doi: 10.12737/5454.

Please cite this article in press as: Korotkiy I.A., Korotkaya E.V., and Kireev V.V.Energy efficiency analysis of the sea buckthorn (*Hippophae rhamnoides*) fruits quick freezing. *Foods and Raw Materials,* 2016, vol. 4, no. 1, pp. 110–120. doi: 10.21179/2308-4057-2016-1-110-120.