INTERNATIONAL JOURNAL ON ORANGE TECHNOLOGY
https://journals.researchparks.org/index.php/IJOT e-ISSN: 2615-8140 | p-ISSN: 2615-7071
Volume: 4 Issue: 9 | September 2022

Theoretical Foundations of the Process of Steaming Cocoons in a Vacuum Device

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Annotation: This article highlights the importance of the cocoon steaming process for producing quality raw silk. And also provides information about the advantage of vacuum cocoon steamer. Since the vacuum pressure, temperature and volume of water in the evaporation chamber are constant, isobaric, isothermal and isochoric processes of thermodynamics are also studied. Information on absorption and adsorption processes associated with the entry of liquid into the cocoon is also provided.

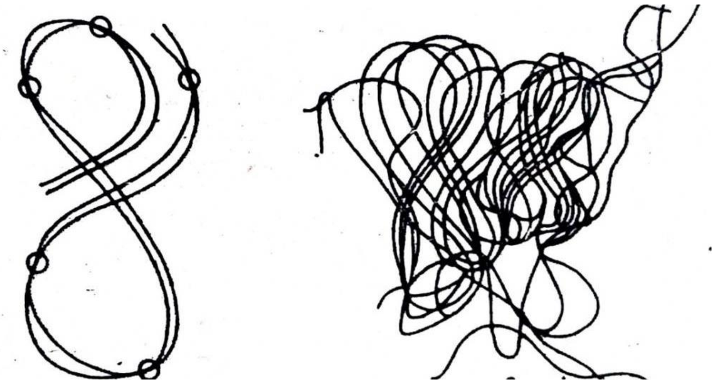
Keywords: cocoon, steaming, steamer, silkworm, silk fiber, isothermal process, isobaric process, isochoric process, cocoon shell.

INTRODUCTION

In technological processes of production of raw silk, which is an expensive textile raw material, along with the quality parameters of cocoon raw materials, the technological processes of preparing dry cocoons for spinning have a serious effect on the quality indicators and quantity of produced raw silk, silk products and fabrics. In this regard, it is important to increase the competitiveness of silk products in the world market in order to further improve the consumer properties of silk fiber [1].

LITERATURE ANALYSIS AND METHODOLOGY

These technological processes mainly consist of dry cocoon sorting, steaming, and the technological processes of finding a single silk thread. Among these processes, especially the technological process of cocoon steaming is one of the important technological processes [2]. Because in the technological process of cocoon steaming, the better the cocoon shell is steamed, the better the surface of the cocoon shell is washed, the better the knots formed by the silkworm during the cocooning process, the places where the silk threads stick to each other, and the sericin substance on the surface of the silk thread dissolves better softens and ensures even washing (see picture 1).



a) b)

Picture 1. To form a cocoon shell by a silkworm appearance of discarded cocoon threads.

a - joining of rings by a silkworm;

b – ring packets.

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As you can see from picture 1, the silkworm makes a ring from the silk fibers coming out of the silk gland during the cocoon formation and cuts it into eight bundles and glues these silk fibers together. That is, during the production of the silkworm cocoon shell, the silk fibers are put together in a package of 15-20 rings in eight cases. According to E. B. Rubinov, a 1000 m long cocoon thread has up to 6 million overlapping places. If the length of the ring is 0.63-1.32 cm, when it is blown at a speed of 1.67 m/s, the vibration of the cocoon is 255-530 [3]. Due to the softening and partial washing of these silk fibers in the technological process of preparation for cocoon spinning, that is, in the steaming technological process, silk fibers on the surface of the cocoon can be continuously spun from the surface of the cocoon in the direction opposite to the silkworm's cocooning process[4].

When a silk fiber is cut crosswise and seen through a microscope, two silk fibers are stuck together. The composition of silk fiber shows that it consists of 70-80% fibroin and 20-30% sericin[5].

Based on the above, determining the optimal steaming technological parameters of the cocoon and using these optimal parameters in the steaming process, in turn, will facilitate the technological processes of finding the end of a single cocoon silk thread from the surface of the cocoon and pulling out a continuous cocoon thread. As a result, it is possible to increase the amount of raw silk that can be spun from the cocoon and to ensure that the unevenness of the linear density of the spun raw silk is reduced. This, in turn, leads to an increase in the quality of raw silk [6].

The technological process of cocoon steaming takes place mainly depending on parameters of cocoon steaming time, water temperature and air pressure in the steaming chamber.

So, the technological process of cocoon steaming, in turn, is carried out based on the laws of thermodynamics, including isothermal, isobaric and isochoric processes.

Therefore, we directed our further research work to the study of thermodynamic and chemical processes, based on the laws of thermodynamics, occurring in the technological process of cocoon evaporation.

For this purpose, theoretical studies were carried out on technological processes of cocoon steaming in water at different temperatures, vacuum pressures and for different periods of time using a universal cocoon steaming chamber (see picture 2).

Picture 2. Overview of the universal vacuum cocoon steamer.

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DISCUSSION AND RESULTS

Since the vacuum pressure in the vaporization chamber is constant, the technological process of universal cocoon vaporization in the chamber takes place through the isobaric process of thermodynamics. In an isobaric process, the system pressure is constant, that is:

$dP=0, P=const$ (1)

We construct the equations of state for the isobaric process:

$P_1V_1=RT_1; P_2V_2=RT_2$

From the ratio of the equations of state, we derive the expression of the Gay-Lussac law:

$$\frac{V_1}{V_2}=\frac{T_1}{T_2} \text{ or } V_1T_2=V_2T_1 \quad (2)$$

It can be seen that in an isobaric process, the volume is directly proportional to its absolute temperature (Gay-Lussac's law) [7].

To find the work of expansion in an isobaric process, we use dl=P*dv:

$$l=\int_{V_1}^{V_2} pdV = p(V_2 - V_1) \quad (3)$$

Since $P_1V_1 = RT_1$ and $P_2V_2 = RT_2$

$L = R (T_2 - T_1)$ (4)

The amount of heat supplied to the system in an isobaric process is found as follows:

$$q=\int_{T_1}^{T_2} c_p dT = c_p\Big|_{t_1}^{t_2}(t_2 - t_1) \quad (5)$$

According to the first law of thermodynamics:

$\Delta u=q - l= c_p(T_2-T_1)-R(T_2-T_1)=(C_p -R)(T_2 -T_1)=C_v (T_2 -T_1)$

When the entropy change is s_r= const:

$s_2-s_1=c_p\ln(T_2/T_1)$ (6)

That is, the change of entropy with respect to the change in temperature is also logarithmic in the isobaric process, but since $c_P> c_V$, the isobar is located more horizontally in the T-s–diagram (see Picture. 3).

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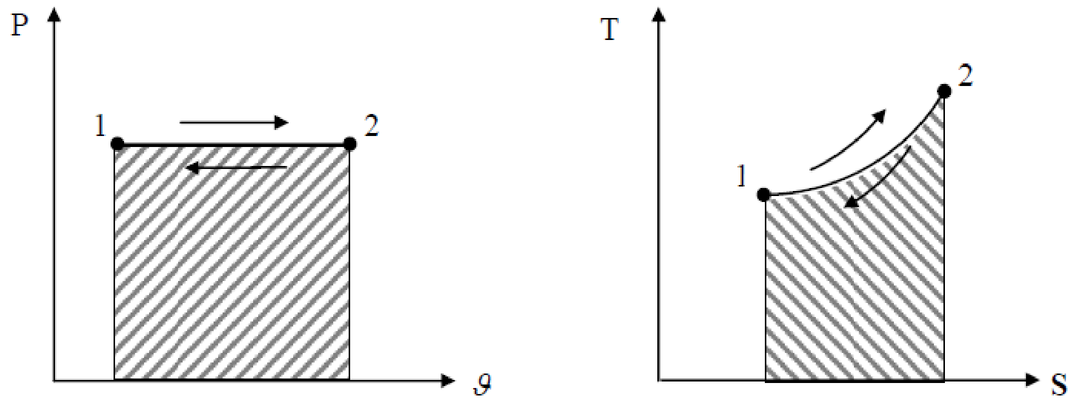

Picture 3. Representation of the isobaric process in P-V and T-s diagrams.

As can be seen from figure 3, P-V diagram has $V_1<V_2$ at $P_1=P_2$, which means volume increases while pressure remains unchanged. And in the T-s diagram, when $T_1< T_2$, then $s_1<s_2$, that is, as the temperature increases, the entropy also increases. Therefore, the higher the temperature of the liquid, the greater its specific volume. In an isobaric process, when heat is added to an ideal gas, a 1-2 expansion process occurs, and when heat is removed, a 2-1 compression process occurs. At the same time, an isothermal process also takes place in the chamber due to the fact that water of a certain constant temperature is introduced into the chamber after air is sucked from the evaporation chamber.

In an isothermal process, the temperature is constant, i.e. dT=0 T=const. Consequently:

$PV = RT = const$

We construct the equations of state for an isothermal process:

$P_1V_1=RT_1;\ P_2V_2=RT_2$

From the ratio of the state equations of the system, we form the expression of the Boyle-Marriott law:

$$\frac{P_1}{P_2}=\frac{V_2}{V_1} \text{ or } P_1V_1=P_2V_2...P_nV_n=const \qquad (7)$$

In an isothermal process, pressure and specific volume are inversely proportional to each other. Fluid pressure increases during isothermal contraction, decreases during expansion (Boyle-Marriott cone) [8].

The work done in an isothermal process is found as:

$$l=\int_{V1}^{V2} PdV=\int_{V1}^{V2}\frac{RT}{VdV}=RT\ln\left(\frac{V_2}{V_1}\right)=RT\ln\left(\frac{P_1}{P_2}\right) \qquad (8)$$

Since the temperature does not change, the internal energy of the liquid remains unchanged in this process ($\Delta u=0$) and all the heat supplied is converted into the work of expansion in the isothermal process:

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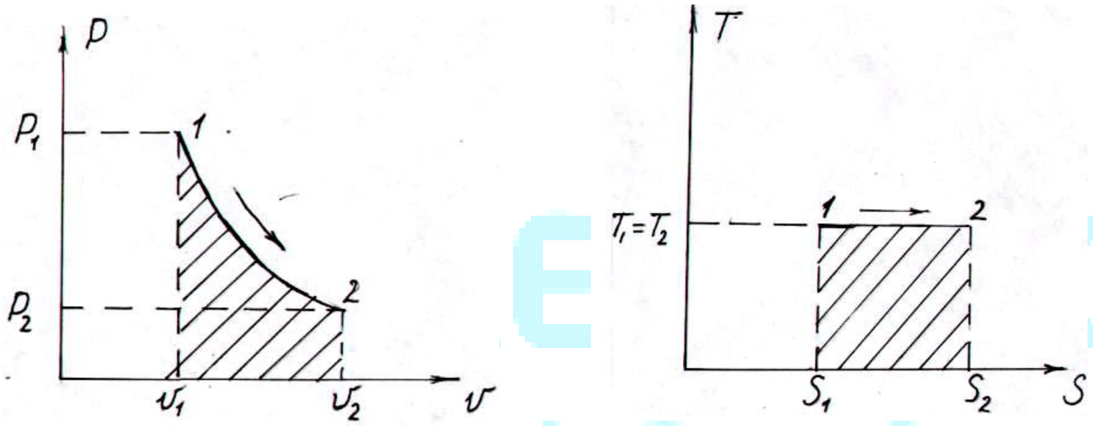
$$q = l = \int_{V1}^{V2} PdV = \int_{V1}^{V2} \frac{RT}{VdV} = RT \ln\left(\frac{V_2}{V_1}\right) = RT \ln\left(\frac{P_1}{P_2}\right) \qquad (9)$$

In an isothermal process, since the temperature is constant, $\Delta u=0$.

The entropy change in an isothermal process is found as:

$$s_2 - s_1 = \int_1^2 \frac{dq}{T} = \frac{g}{T} = R \ln \frac{P_1}{P_2} = R \ln\left(\frac{V_2}{V_1}\right) \qquad (10)$$

The graph of the isothermal process in P-V coordinates according to equation (7) is an equilateral hyperbola, and the coordinate axes serve as asymptotes (see Picture 4).



Picture 4. Representation of the isothermal process in P-V and T-s diagrams.

As can be seen from figure 4, the P-V diagram has $V_1<V_2$ at $P_1>P_2$ when the temperature does not change, that is, the volume increases when the pressure decreases. And in the T-s diagram, when $T_1=T_2$, $s_1<s_2$, that is, the entropy increases when the temperature does not change.

Also, since the evaporation chamber is a constant volume system, an isochoric process also occurs.

In an isochoric process, the volume of the system does not change, i.e. dV=0 or V= const. We construct the equations of state for the isochoric process:

$P_1V_1=RT_1$; $P_2V_2=RT_2$

From the ratio of equalities, the expression of Charles's law is formed, since $V_1=V_2$=const.

$$\frac{P_1}{P_2} = \frac{T_1}{T_2} \text{ or } P_1T_2=P_2T_1 \qquad (11)$$

It can be seen that in an isochoric process, the pressure is directly proportional to its absolute temperature (Charles' law).

The work of expansion is zero in an isochoric process because dV=0.

In the isochoric process, the amount of heat supplied to the working body is found as follows, under the condition C_v=const:

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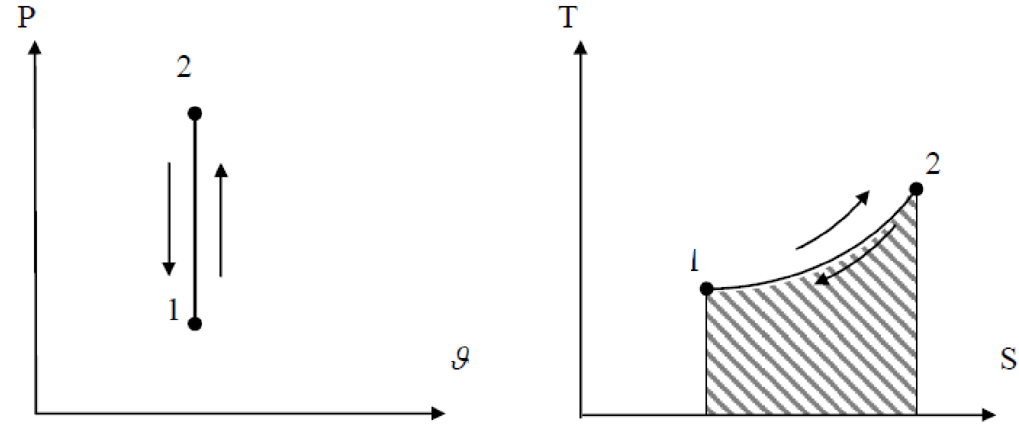
$$q = \int_{T_1}^{T_2} C_V dT = C_V (T_2 - T_1) \quad (12)$$

The entropy change is found as:

$$s_2 - s_1 = C_V \ln\left(\frac{P_2}{P_1}\right) = C_V \ln\left(\frac{T_2}{T_1}\right) \quad (13)$$



Picture 5. Representation of the isochoric process in P-V and T-s diagrams.

Picure 5 shows that in the P-V diagram, the pressure changes while the volume does not change, and in the T-s diagram, when $T_1<T_2$, it becomes $s_1<s_2$, that is, as the temperature increases, the entropy also increases. In other words, when heat is given to an ideal gas, a 1-2 process occurs, and when heat is removed, a 2-1 process occurs.

In addition, after the air inside the steaming chamber is sucked by a vacuum pump, water of a certain temperature is introduced into the chamber. Since the air inside the cocoons in the vacuum chamber is also sucked in, water of a certain temperature begins to enter them quickly. The process of absorption occurs when water is absorbed into the cocoons. (Absorption (from the Latin absorbio — absorption, absorbeo — to swallow) — volumetric absorption of substances (absorbates) in a solution or gas mixture into a solid or liquid (absorbent) (see Picture 6)).

Absorption of gases into liquids is used in oil refining, coke benzene and other industries. Absorption, based on the difference in solubility of gases in vapors and liquids, is used in technology for purification and separation of gases and their separation from vapor-gas mixtures. The opposite process to absorption is called desorption, which is used to separate the gas absorbed by the solution and regenerate the absorbent.

At the same time, as a result of the wetting of the surface of the cocoons, the adsorption process also occurs (Adsorption — concentration, absorption of liquid or gaseous substances (adsorbates) on the surface of solid or liquid substances (adsorbents) (see Picture 6)).

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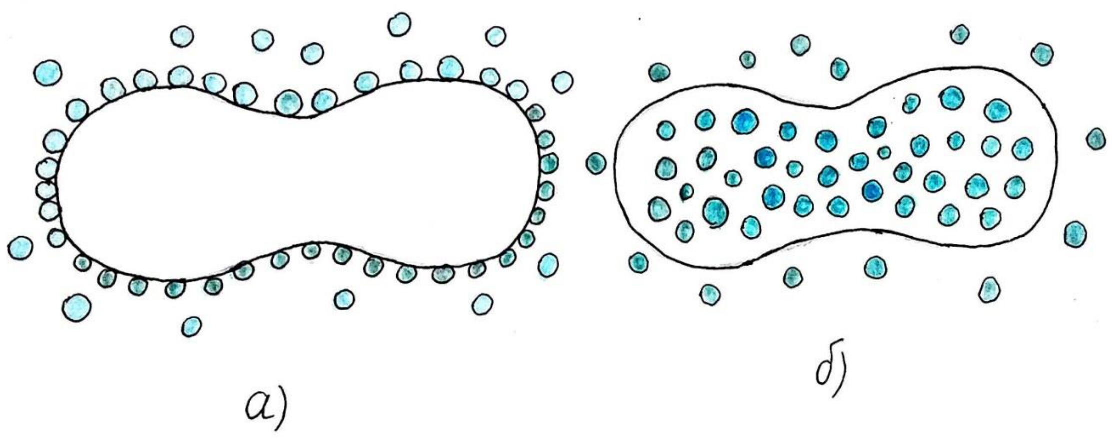

Picture 6. Adsorption and absorption processes (a-adsorption, b-absorption) when water enters the cocoon.

As can be seen from Fig. 6, when water is introduced into the cocoon, the surface of the cocoon, i.e., the shell, becomes wet during the adsorption process (picture 6 a). During the absorption process, when water is introduced into the cocoon, the interior of the cocoon is filled with water (picture 6 b).

So, absorption and adsorption processes occur simultaneously when water enters the cocoons inside the vaporization chamber. In addition, the cocoons in the vacuum chamber where the air is drawn from the universal vacuum cocoon steamer heats up and increases the porosity of the cocoons. The penetration of water into the cocoon depends on the porosity of the cocoon shell. In cocooning, the nature of placing the shell in layers, rings in packets, and packets in layers, results in the formation of voids in individual short sections of the shell. This space is expressed by the degree of porosity of the cocoon and is calculated by the following equation.

$\Pi = [\ 1- (M / 1,37 \cdot T) * 100]\ \%$ (14)

where Π - is the porosity of the cocoon shell, %;

1.37 - density coefficient of silk;

M – strength of cocoon shell, mg/mm2;

T – thickness of cocoon shell, mm.

CONCLUSION

The more porous the cocoon shell is, the easier it is to prepare it for cocooning, that is, to absorb water and soften sericin uniformly on the layers of the cocoon [9].

Thus, the cocoon steaming process in the universal cocoon steaming chamber is a complex thermochemical process involving the entry of hot water at a certain temperature into the cocoon and the evaporation of the cocoon.

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