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APPLICATION OF MULTI-AGENT PROGRAMMING FOR MODELING THE VISCOSITY STATE OF MASH IN ALCOHOL PRODUCTION

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Abstract. *In alcohol production from starch-containing raw materials, it is essential to know the dynamic viscosity of the resulting solution. The main drawback of control systems in the solution preparation process is the lack of viscosity monitoring. This prevents the use of processing modes that would ensure efficient execution of the subsequent thermoenzymatic treatment of the solution. This work is dedicated to examining the qualitative impact of the timing of enzyme addition on the change in the dynamic viscosity of the solution, aiming to improve the quality of the process control during its preparation. The study was conducted in the free multi-agent programming environment NetLogo, which is used for modeling complex systems evolving over time.*

Keywords: optimization models, NetLogo, dynamic viscosity, alcohol production

ZASTOSOWANIE PROGRAMOWANIA WIELOAGENTOWEGO DO MODELOWANIA ZMIAN LEPKOŚCI WSADU W PRODUKCJI ALKOHOLU

Streszczenie. *Przy produkcji alkoholu z surowców skrobiowych kluczowe jest poznanie lepkości dynamicznej uzyskanego roztworu. Główną wadą istniejących systemów kontrolujących proces przygotowania roztworu jest brak monitorowania lepkości. To uniemożliwia stosowanie takich trybów obróbczych, które zapewniłyby efektywne przeprowadzenie następnej operacji termoenzymatycznej obróbki roztworu. Artykuł poświęcony jest analizie wpływu czasu dodawania enzymów na zmianę lepkości dynamicznej roztworu w celu poprawy jakości zarządzania procesem jego przygotowania. Badania przeprowadzono w darmowym środowisku programistycznym NetLogo, które służy do modelowania złożonych systemów rozwijających się w czasie.*

Słowa kluczowe: modele optymalizacji, NetLogo, lepkość dynamiczna, wytwarzanie alkoholu

Introduction

The dynamic viscosity of mash is a critical parameter in alcohol production, as it directly affects the efficiency of the process of processing starch-containing raw materials.

The technological process of alcohol production consists of three main stages [8]:

1. preparation of mash from starchy raw materials, such as grain,
2. yeast generation and fermentation of the wort by yeast,
3. alcohol extraction from the culture liquid (wash) through distillation and rectification.

All stages of production involve processing the raw materials in a crushed form, and the transition to each subsequent stage is carried out by pumping through pipelines with the help of pumps. Dynamic viscosity determines the mobility of the mash and the flowability of the water-grain mixture during transportation. This leads to better and faster cooking of the mash and allows for energy savings, reduction in cooking temperature regimes, lower raw material consumption, improved fermentation processes, and ultimately increases the yield and quality of the alcohol.

Therefore, the process of mash preparation, which takes place at the initial stage of alcohol production, is a crucial step that influences the overall production efficiency. It is at this stage that water and ground grain are mixed in the appropriate ratio (1:3).

The challenge of working with water-grain suspensions made from grain raw materials lies in the sharp increase in their dynamic viscosity when heated from 50°C to 80°C, and in some cases up to 90°C. Experimental data show that the dynamic viscosity starts to rise sharply during the swelling of starch grains and the onset of gelatinization [8, 11]. This is due to the fact that the two-phase mixture (water-grain particles) changes its structural-mechanical properties as the gelatinization process of the starch begins. Studies [9, 12] focus on determining the quality indicator of starch-containing mash preparation, specifically dynamic viscosity, which remains insufficiently explored to date.

Depending on the grain type, starch gelatinization begins at different temperatures: at approximately 50°C, the initial release of starch occurs; in the temperature range of 55-65°C, uncontrolled starch release takes place, initiating gelatinization; and in the 65-90°C range, critical starch release from the grains occurs. These processes are accompanied by an increase in the dynamic viscosity of the medium, leading to specific challenges in conducting technological processes due to reduced fluidity.

For different grain crops, the average dynamic viscosity values are as follows: at 65°C – 1267 MPa·s; at 75°C – 1656 MPa·s; at 85°C – 2940 MPa·s [17].

Difficulties arise when using high-concentration suspensions, as they are characterized by increased viscosity. This further complicates the process of pumping the water-grain mixture through the pipeline to the thermo-enzymatic processing unit, leading to additional steam consumption for diluting the mixture.

To reduce the viscosity of the water-grain suspension, enzyme preparations such as α-amylase are used. These enzymes help break down starch into simpler molecules, reducing dynamic viscosity without affecting the loss of fermentable substances during liquefaction. Therefore, dissolving the grain in water with enzymatic components is the first step in preparing the mash for alcohol production.

Main stages of these processes include absorption of water by the grain and enzyme activity.

The degree of gelatinization depends on the temperature regime, enzyme activity, their quantity, and the timing of their addition to the mixture. Studies [1, 6, 13] analyze the impact of temperature and enzymes on viscosity, which, in turn, depends on various input factors such as grain type, degree of grinding, moisture content, and other parameters.

Maintaining the optimal technological conditions and specified parameters for the enzymes allows for the control of the starch hydration process, thus regulating the dynamic viscosity of the mixture at different stages and predicting the moment of gelatinization.

Let's examine in detail the effect of enzyme action on the gelatinization process.

At the initial stage of heating the mixture, the addition of enzymes accelerates the process by breaking down starch molecules before reaching the gelatinization temperature. This helps to reduce the dynamic viscosity of the suspension at the beginning of the process.

At the stage of reaching the gelatinization temperature, the addition of enzymes allows for timely intervention in the breakdown of starch, ensuring that the enzymes are most effective during the gelatinization process.

After reaching the gelatinization temperature, the addition of enzymes will complete the breakdown of residual starch, helping to stabilize the dynamic viscosity of the mixture and preparing it for the subsequent thermo-enzymatic treatment process.

The selection of the correct timing for enzyme addition depends on specific process conditions, including the type of grain, temperature, and mixture structure.

Thus, the dissolution of grains creates conditions for gelatinization, which significantly increases the dynamic viscosity of the mixture. High viscosity complicates transportation, mixing, and enzymatic treatment of the mixture. Conversely, low viscosity facilitates these processes by ensuring even distribution of enzymes, but does not provide significant starch release. Optimal viscosity, on the other hand, ensures uniform mixing of the mixture components, which promotes more effective enzymatic action, reduces energy costs, and enhances overall energy efficiency in production. Studies [2, 5, 10] investigate the issue of viscosity in grain mixtures, which complicates mixing, starch hydrolysis, and fermentation, thereby reducing the efficiency of alcohol production.

At the same time, effective management of these processes allows for the optimization of dynamic viscosity, which is critical for energy efficiency and the quality of alcohol production. The study [3] presents an experimental application of an adaptive control strategy that enables the regulation of mash density in alcohol fermentation. In [15], a continuous quality control system for mixture preparation is proposed, utilizing modern information technologies.

Therefore, the process of starch release (viscosity) and its derivatives during the preparation of the mixture is the most crucial from the perspective of production energy efficiency and product quality.

Determining the state of the mixture, which requires the timely application of enzyme preparations in the correct dosage to ensure the optimization of energy efficiency and the quality of the final product at the stage of mixture preparation, is a relevant issue.

The analysis of the literature has confirmed that the stage of preparing grain raw materials in the alcohol production process requires detailed study [4, 14].

1. Problem statement

To study processes, their modeling is effective [7]. The objective of this work is to obtain a detailed understanding of the effect of the timing of enzyme addition on the change in mixture dynamic viscosity to improve the quality of process control during mixture preparation.

This task is addressed by incorporating into the model various particle sizes that define grind coarseness, different quantities of enzyme preparations (relative to the total mass), and temperature regimes.

2. Modeling environment

The modeling was conducted in the free multi-agent programming environment, NetLogo, which is used for simulating complex systems that evolve over time [16].

A key feature of such models is their distributed nature, or multi-agent structure. Each model typically consists of a large number of relatively simple entities – agents. The systemic effect is achieved through the interaction of these simple entities.

An integral aspect of the model-building process in NetLogo is visualization, which allows the model developer to dynamically control numerous visual attributes. Additionally, the NetLogo environment supports the construction of various types of graphs, making it a comprehensive platform for numerical research into the behavior of the developed models.

3. Program operation

The developed model implements the algorithm as follows: a certain number of grain and enzyme turtles are created, and the user sets the ratio of one quantity to the other. These turtles "dissolve" (become invisible), increasing the viscosity of the medium (represented by color) with a probability defined by the user.

```
to setup
  clear-all
  set-default-shape turtles "circle"
  ask n-of grain patches [
    sprout 1 [ set color red ]
  ]
to setup-plot
  set-current-plot "Grain Rate"
  set-plot-pen-mode 0
  set-plot-x-range 0 (ticks + 1)
  set-plot-y-range 0 count turtles
  ;; Create a pen named "Red Turtles" and set its
color to red
  create-temporary-plot-pen "Red Turtles"
  set-current-plot-pen "Red Turtles"
  plot 0
end
```

At each iteration, if the random-float 100.0 function returns a number less than the given probability, the turtle changes its color to temporary yellow to track the turtles that are set to dissolve. After this, all yellow turtles are set to 'hidden? true'. Additionally, at the same time, the color of all patches is incremented by +0.004.

```
to convert-turtles
  let num-convert count turtles * 0.1 ;; Find 10%
of the total number of red agents
  ask n-of num-convert turtles [
    set color yellow ;; Change the color of a
random 10% of the red agents to yellow
  ]
  ;; Check if all turtles have turned yellow
  ifelse count turtles with [color != yellow] = 0
[
    set flag true ;; Set a flag
  ] [
    set flag false ;; If there is at least one
turtle that is not yellow, reset the flag
  ]
end
```

The dissolution continues until the medium reaches the desired viscosity. Specifically, this occurs when the color of all patches reaches 95. Once this value is attained, the program stops, leaving some turtles in the environment that have not dissolved.

```
to go
  if all? turtles [pcolor > count-color]
  [set decays 0 stop]
  set decays 0
  ask turtles with [color = red or color = green]
    [ if random-float 100.0 < temperature
        [ set color yellow
          set decays decays + 1] ]
  display
  ask turtles with [color = yellow]
    [
      set color red - 3
      set hidden? true
     ask patch-set patches
       [
        if pcolor < count-color
        [
     set pcolor pcolor + 0.004
        ]
      ]
  ]
```

4. Main results

The number of grain and enzyme turtles is set by the user through the Grain and Enzyme sliders, respectively. The initial interface of the model is shown in Figure 1.

The Temperature slider allows changing the temperature to simulate the probability of turtle "dissolution" in the subsequent iterations. The higher the value set on the slider, the faster the required number of turtles will dissolve in fewer iterations.

The Grain and Enzyme monitors display the current number of Grain and Enzyme turtles, respectively. The Decays monitor shows the number of turtles that are set to "dissolve" at the current moment. The Grain Rate and Enzyme Rate graphs depict the dynamic changes in the number of the first and second type of turtles, respectively. The Decay Rate graph shows the rate of turtle "dissolution".

Over time, the turtles change color to yellow (dissolve) and the environment gradually changes its viscosity (color).

Let's analyze the behavior of the water-grain-enzyme system when changing the solution temperature in the mixing zone.

Set the Grain slider to 1200 turtles and the Enzyme slider to 10 turtles, corresponding to a grain proportion of 35% of the total mass and an enzyme proportion of 0.06%.

To determine the effect of temperature on the rate of starch release, we will vary the temperature value, assess the number of grains that remain undissolved, and analyze the dissolution rate of the elements.

For the first experiment, set the Temperature slider to 50°C (see Figure 2).

Based on the results from ten runs of the model, at a temperature of 50°C, 13% of the grains and 17% of the enzymes remained undissolved. The maximum dissolution rate was 599 elements per first tick, or 50% of the elements, after which the dissolution rate began to decline.

Increase the temperature to 55°C with the previous amount of enzymes (see Figure 3).

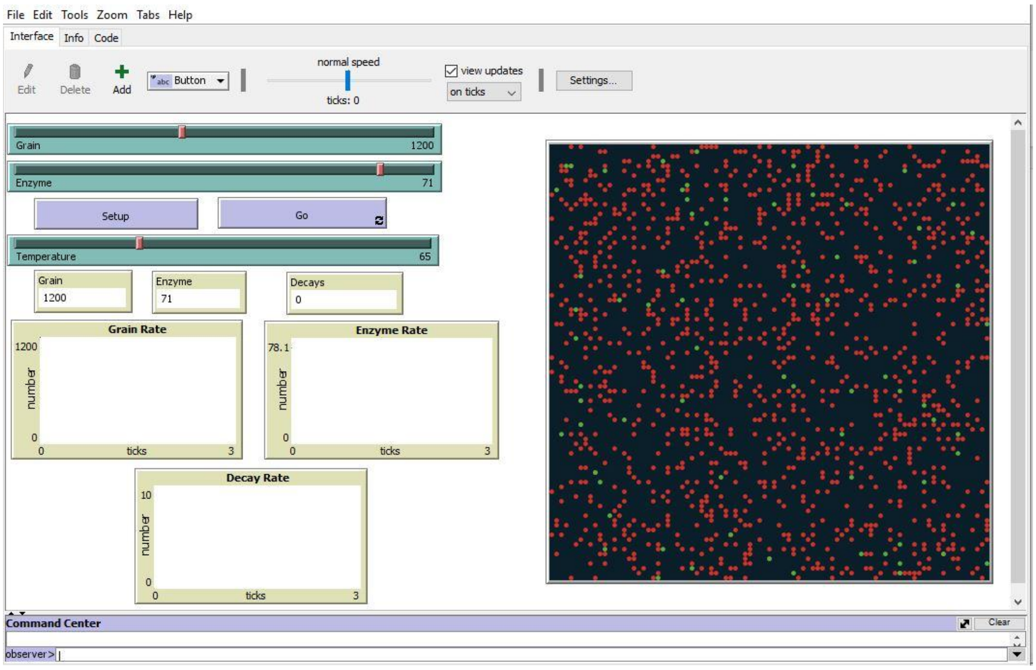

Fig. 1. Initial model interface

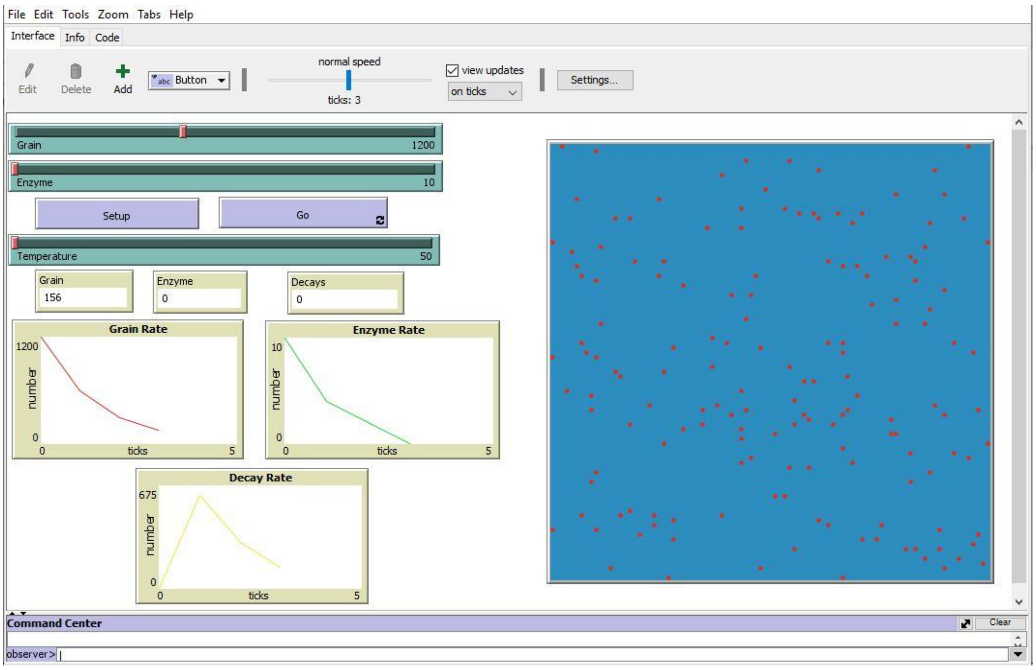

Fig. 2. Interaction of turtles at temperature 50°C

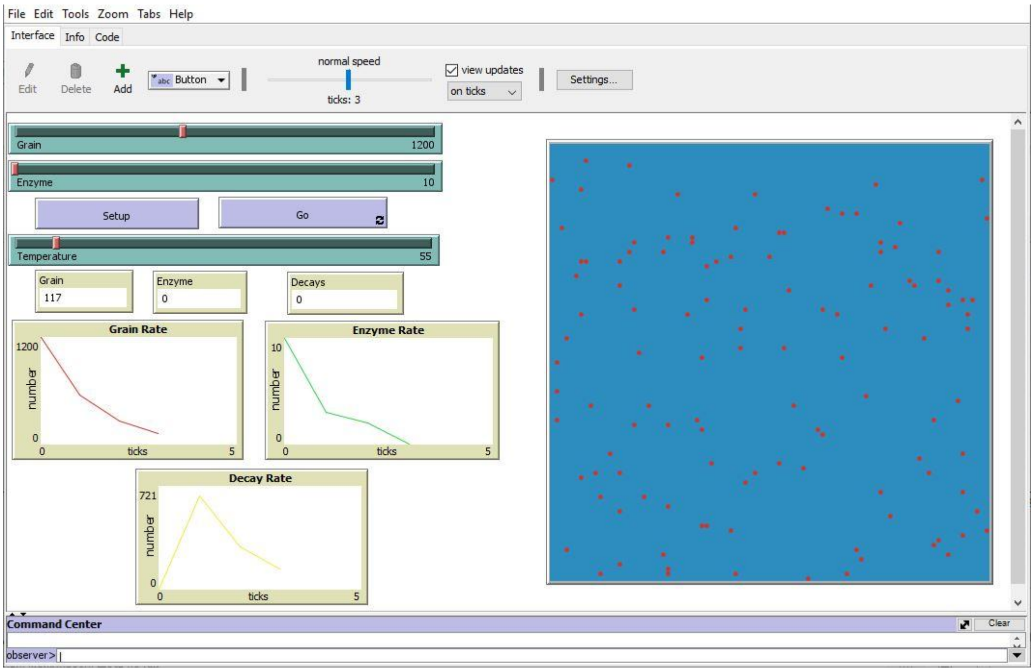

Fig. 3. Interaction of turtles at temperature 55°C

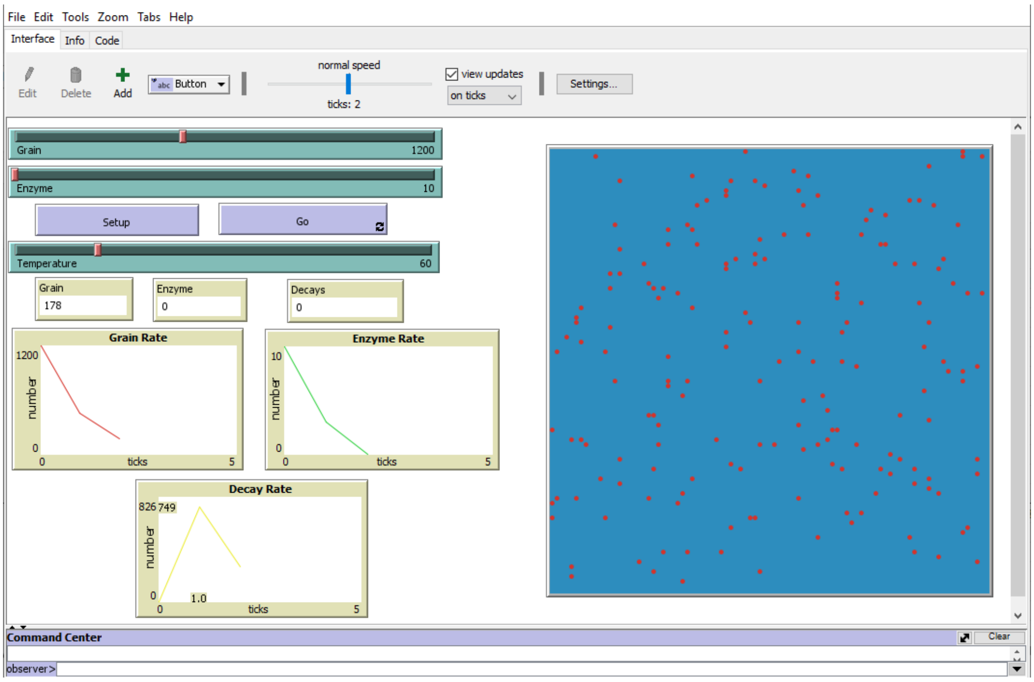

Fig. 4. Interaction of turtles at temperature 60°C

Based on the results from ten runs of the model, at a temperature of 55°C, 12% of the grains and 10% of the enzymes remained undissolved. The maximum dissolution rate was 652 elements per first tick, or 54% of the elements.

Set the temperature to 60°C (see Figure 4).

Based on the results from ten runs of the model, at a temperature of 60°C, 10% of the grains and 8% of the enzymes remained undissolved. The maximum dissolution rate was 732 elements per first tick, or 60% of the elements.

By incrementally increasing the temperature to 95°C in 5°C steps, data was obtained on the number of residual undissolved grains and enzymes at each temperature, as well as the dynamics of the dissolution rate of the elements. The results are presented in Figures 5 and 6. The conducted research revealed that the peak point for gelatinization occurs within the temperature range of 75-83°C, which aligns with the data from the literature. Within this range, there is an observed minimum amount of undissolved components due to the increased dissolution rate of the mixture components. Further increases in temperature beyond this range lead to higher dynamic viscosity of the mixture, which inhibits the dissolution process. The established temperature interval suggests that the optimal addition of enzymes at these temperatures will enhance production efficiency. By timing the enzyme addition within this specific temperature range, the production process can be better optimized for achieving maximum effectiveness in dissolution and overall production quality.

The study conducted provides qualitative insights, as it does not account for the specific physical characteristics of different grain types and enzyme preparations. The findings will serve as a foundation for further research, which will incorporate factors such as the type of grain, grind size, hydration ratio of the mixture, and the rate of temperature increase. This subsequent research will aim to refine and enhance the understanding of how these variables influence the gelatinization and dissolution processes in alcohol production.

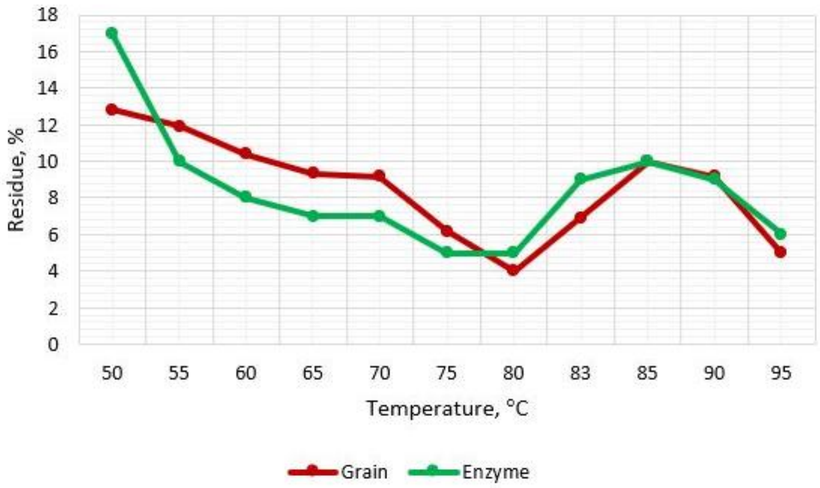

Fig. 5. Dependence of the percentage of undissolved grains and enzymes on temperature

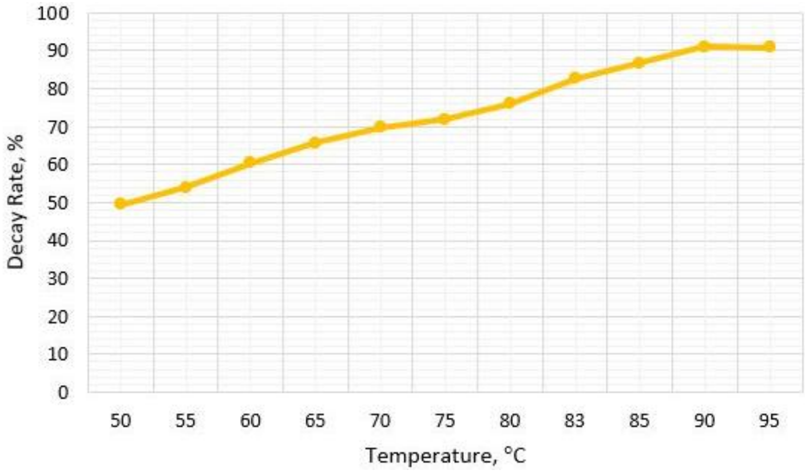

Fig. 6. Dynamics of dissolution rate (%) with increasing temperature

5. Conclusion

Thus, a model has been developed in the free multi-agent programming environment NetLogo, which allows for the investigation of the impact of temperature on the rate of starch release in the mixture and the dynamics of the dissolution rate of elements. The simulation of dynamic viscosity changes in the mash during alcohol production has determined that the optimal period for enzyme addition corresponds to a mash temperature range of 75-83°C. Within this range, an increase in the dissolution rate of mixture components results in a minimum level of undissolved components. This observation suggests that enzyme addition at these specific temperatures will enhance process efficiency and optimize production.

The results provide a qualitative understanding of the effect of the timing of enzyme addition on the dynamic viscosity of the mixture, aiming to improve the quality of the process control for preparing the mixture.

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