Lecture Notes in Networks and Systems 463

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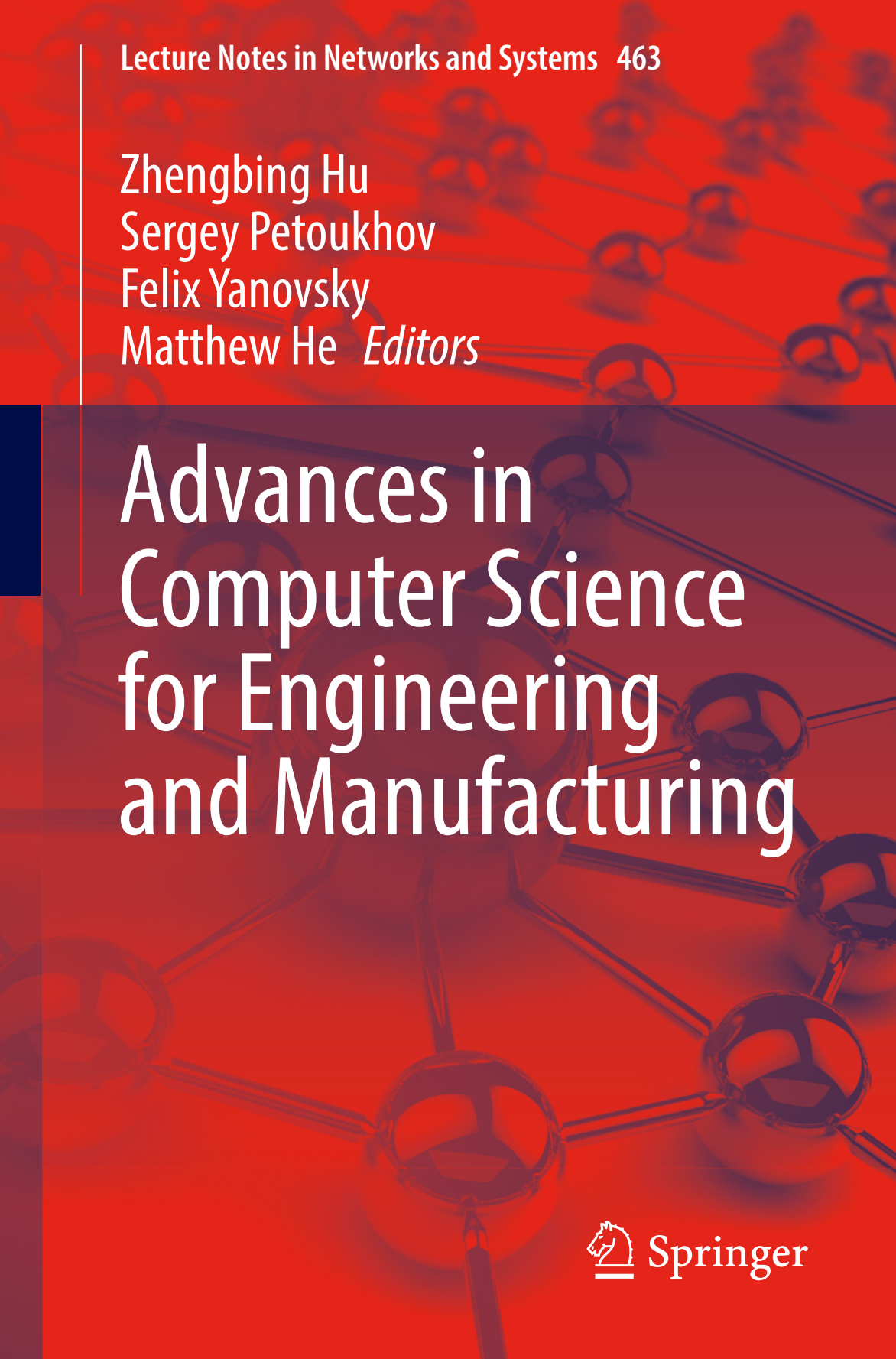
Matthew He *Editors*

# Advances in Computer Science for Engineering and Manufacturing



Springer

# Lecture Notes in Networks and Systems

Volume 463

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# Advances in Computer Science for Engineering and Manufacturing

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ISSN 2367-3370 ISSN 2367-3389 (electronic)
Lecture Notes in Networks and Systems
ISBN 978-3-031-03876-1 ISBN 978-3-031-03877-8 (eBook)
https://doi.org/10.1007/978-3-031-03877-8



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The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

# Preface

The development of artificial intelligence systems and their applications in various fields belongs to the most urgent tasks of modern science and technology. One of these areas is engineering and manufacturing, whose development is aimed at increasing the life support of the world's population, including the tasks of developing industry, agriculture, medicine, transport, etc. The rapid development of artificial intelligence systems requires the intensification of training of a growing number of relevant specialists. At the same time, artificial intelligence systems have significant perspectives of their application inside education technologies themselves for improving the quality of training of specialists taking into account personal characteristics of such specialists and also the emergence of new computer devices.

The International Symposium on Engineering and Manufacturing (December 24–26, 2021, Kyiv, Ukraine) has its purpose to present new thematic approaches, methods, and achievements of mathematicians, physicians, biologists, and technologists and also to attract the additional interest of different specialists to this perspective theme. Its proceedings additionally includes articles on specific tasks in various fields, where artificial intelligence systems can be applied in the future with great benefit.

The Symposium is organized jointly by the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute," National Aviation University, Kyiv National University of Construction and Architecture, Hubei University of Technology, Polish Operational and Systems Society, and International Research Association of Modern Education and Computer Science.

The best contributions to the conference were selected by the programed committee for inclusion in this book out of all submissions.

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# Contents

# Computer Science for Manage of Natural and Engineering Processes

# Analysis of Virtual Promotion of a Product

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**Abstract.** Over the past ten years, our scientific team has completed more than thirty projects in the field of search engine optimization. The results of these projects indicate the existence of a new branch of marketing - virtual promotion. Therefore, the purpose of this work was to describe a new control object. The work formulates the definition, purpose, structure and metrics for evaluating the effectiveness of virtual promotion of a product. The object includes two channels: knowledge distribution and marketing. One plays role of logistics of knowledge about a product in virtual space, but another controls this process on-line. On the basis of this, a diagram of the business process of virtual promotion is proposed. A new approach to the management of this object is also proposed through the solution of four problems: structural parameter synthesis, coordination, generation of a semantic kernel, and performance evaluation. As a result, a new scheme of the business process of virtual promotion was proposed. The schema is based on the new idea that the knowledge about a product is being presented as knowledge unit named semantic kernel of web content.

**Keywords:** Virtual promotion · Business process · IDEF framework

## 1 Introduction and Related Works

The classic definition of a marketing channel speaks of the interaction of the manufacturer, buyer and intermediary in order to benefit from the maximum satisfaction of a given need. There are three main functions of such a channel. The first is to satisfy the consumer's request. The second is to stimulate demand. And the third – after sales service. The paper focuses on the second function – stimulating demand. But the work explores a new form of marketing channel – virtual promotion.

The main goal of virtual promotion is to increase the level of sales of goods or services due to technologies that exist in cyberspace. Virtual promotion has the same nature as the logistics channel [1]. We will assume that virtual promotion is a system where there are two channels (sub-systems). The first sub-system has the function of distributing knowledge. The second is the marketing of knowledge about a product or service.

The first channel forms the technology of information transfer (knowledge) about the product in cyberspace. It concentrates actions on transportation, storage and retrieval of information about a product depending on the needs of a potential buyer. To simplify, we


Z. Hu et al. (Eds.): ISEM 2021, LNNS 463, pp. 3–13, 2022.
https://doi.org/10.1007/978-3-031-03877-8_1

assume that there are two functions: the transfer and storage of information (knowledge) about the product. The search function is implemented through a search server.

The distribution of knowledge about the product is formed on the basis of the URI of web resources and web services. This is a set of IP addresses that obey the OSI model [2]. In other words, it is a set of software components that are located on the Internet at specified IP addresses. Each component performs either the function of transmitting or storing information (knowledge) about the product or service.

Another channel is a network of websites, channel telegrams, marketplaces and video blogs. In other words, the marketing channel is formed by real firms that buy and sell information or knowledge about goods or services in cyberspace. The moment of uploading information to the web resource will be considered a transformation or transfer of knowledge about the product in cyberspace.

Thus, the distribution channel sets the configuration of virtual promotion, and the marketing channel - the organizational structure. We will consider a virtual promotion successful when a potential buyer has downloaded the product to their web resource or made a request to obtain information about our product or service from one of the specified IP addresses.

As a result, a two-level system is formed, where levels actively interact. The level of marketing is the manager, and the distribution channel plays the role of the object of management. In addition, it can be argued that virtual promotion is the formation of an organizational system for managing the channel of knowledge dissemination in cyberspace. We will call this organizational structure of market card management. This map shows the two levels at which knowledge about a product or service is transported, stored and transferred to a potential buyer.

Let's try to classify the channel of knowledge dissemination on the basis of known analogues in the field of logistics. At the moment, there are two main logistics concepts: "on time" or "quick response" and the range or "continuous replenishment".

The first concept is based on the assessment of demand for the product. In our case, this approach is not used, because virtual promotion as an innovator forms future channels of communication with potential customers. Of course, it is possible to form any value of the prediction, for example, on the basis of probability theory, but such predictions will be ineffective.

The second concept assumes that product knowledge must be placed at specified points in cyberspace and wait until they are activated by potential buyers. This option is closer to our situation. In this case, we perform three actions: consolidation or concentration, adjustment and scattering.

The first operation means concentrating knowledge about a product or service on a corporate website, telegram channel or video blog. At the same time, these software components must be configured to transfer knowledge on demand over the Internet as quickly as possible.

The second operation means processing knowledge depending on the nature of the request. It is necessary to form a combination of knowledge, we sort them into certain groups or sets. That is, the transformation of knowledge depending on external requests for their receipt. In other words, they need to be reformatted into a form acceptable to the potential buyer to encourage him to buy.

The third operation of "scattering" involves the transfer of knowledge about the product to other storage nodes in these formats. In other words, knowledge on the Internet is duplicated. We will assume that such duplication is also accompanied by reformatting, as we work in an environment of anti-plagiarism programs and components [3].

We will call this channel of knowledge dissemination intensive, because the number of consumers is huge and potentially unlimited. A new marketing channel is a distributed system for disseminating knowledge about a product or service, which consists of the following sequence of steps – Fig. 1 [4].

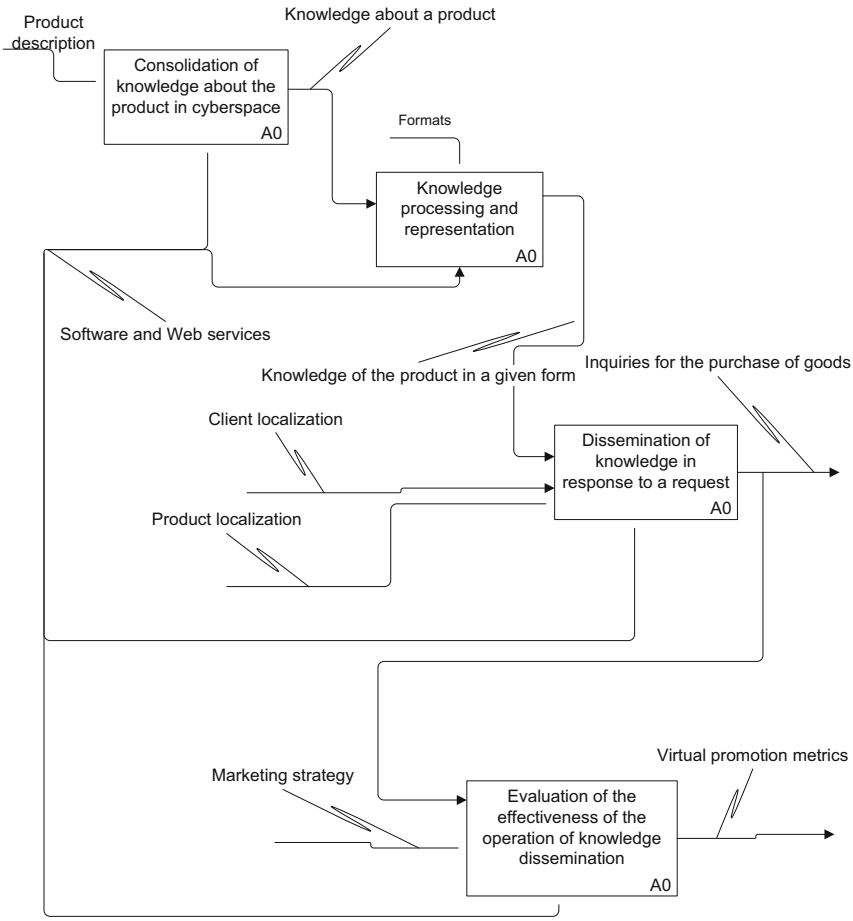


**Fig. 1.** Modern schema of business process of virtual promotion of a product

The standard product description should be transformed into a form that is convenient for distribution in cyberspace. The transformation takes place in two stages. Initially, the text description of the product or service is uploaded to the so-called nodes (hubs). Next, these nodes perform word processing operations in order to present knowledge in the form necessary for further scattering on the Internet. This operation is performed taking

into account the localization of the potential customer's profile and the localization of the product itself. The result of the channel is a request to purchase a given product or service.

Feedback within the channel allows you to get the values of virtual promotion metrics based on the analysis of goals within the marketing strategy of the enterprise and the actual number of sales of goods or services.

The main question remains, what is knowledge about the product. We will assume that knowledge about the product is an algorithm that describes how with the help of this product you can meet a given need for something.

To describe this algorithm to cover a specific need, the user uses a search server (technology), which in a given format performs a search in response to a query in the form of a set of keywords.

This set of keywords describes both the user's request and a specific marketing message that directs the business to cyberspace. The task is to establish in a minimum of time a connection between the user who wants to meet their needs, with a given product and the company that has this product. In other words, the user searches the network for instructions (algorithm) on how to close a certain need for the product. The search is performed using a search engine, content management system, social network, by watching a video or reading a blogger. The task of the marketing service is to lay out in a given format in the virtual space algorithm to cover the needs of the user.

Features of virtual space impose the following restrictions or requirements on the actions of the enterprise:

1) Product description is a set of keywords that are scanned by a search engine. The server generates responses according to a certain algorithm. The answer can consist of a large number of positions. The user usually inspects only the first positions [5–9]. Therefore, an important marketing factor is to be first in response or at least on the first page.
2) HTML product presentation format allows you to select keywords, to which the search server responds when generating responses.
3) The search server registers the number of links to the web page and keywords highlighted in the text.
4) Users register en masse in social networks that have a technological connection with the search server or have built-in search algorithms.
5) Search servers learn to extract keywords from video and audio files.
6) Businesses integrate their information systems with search engines, content management systems and social networks.
7) Mobile applications are widely used to connect with social networks, which allow you to collect data on the real needs of users to cover a particular need.

The above description of virtual promotion as a marketing channel allows us to identify the following research objectives.

## 2 Problem Statement

To highlight the tasks of virtual promotion, you need to determine the class of the object of study (management) in the first approximation, indicate its main properties. This also allows you to give a first estimate of the model type of this object.

The main purpose of the object of study (virtual promotion) is to attract buyers of goods or services. Quantitative assessment of the goal is to determine the number of customers of the product and the income they provide to the company. The function of virtual promotion is to form a marketing channel at two levels: the distribution of knowledge about the product and management (governing body).

The distribution is responsible for downloading, moving and finding knowledge about the product, binding to the level of TCP/IP, URI, URL. That is, to the level of specific placement of knowledge on the Internet.

Management is about determining where in the network and for how long you should place knowledge about a product or service. That is, a promotion map is formed: a list of Internet sites where knowledge about the product is placed to attract a potential buyer. A promotion map is a virtual promotion map that consists of links to URLs and links to each other. In the literature there is an analogue of such a map - a map of the client's travels on the Internet (customer journey map) [6].

The second level determines the form and presentation of this knowledge. That is, the level of management forms the message about the product, which encourages the customer to buy the product. We will call this message the semantic core. According to the classical definition, it is a set of keywords with which the user searches for the desired product on the Internet [6–9].

Next, the control level issues control to perform operations on loading knowledge-message (semantic core) about the product to each node of the virtual promotion map. Then the distribution channel nodes work independently as separate agents.

Also, the second level is responsible for the analysis of promotion, i.e. forms an assessment of its effectiveness. Promotion efficiency is quantified in the form of enterprise income due to cyberspace.

Thus, we can draw the following conclusions about the object of study (virtual promotion) and the conditions of its existence:

1) The object of research includes two levels: logistics of knowledge and management.
2) The level of management forms the semantic core and the map of virtual promotion.
3) The control level sends a signal to load the kernel to the Internet nodes described in the map and monitors the feedback signals about user behavior.
4) Logistics level includes Internet nodes: profiles in social networks; mobile applications connected to the network; messenger channels; video blogger channels; corporate websites and marketplaces.
5) Each node of the logistics level works separately. But it is possible to load the semantic kernel to the node, display the semantic kernel for scanning by the search server and it is guaranteed to find through the search server the semantic kernel that was downloaded earlier. That is, the node performs the three basic functions mentioned above.

6) Each node of the second level is an autonomous system, but all nodes are connected hierarchically according to the map of virtual advancement.

Thus, analyzing the above conclusions regarding the two-level system of virtual promotion, we can talk about the existence of a distributed hierarchical system, which is a composition of two separate hierarchical subsystems.

At first glance, we have the task of coordinating two levels, where the level of marketing plays the role of the management system, and the level of distribution of the object of management. Moreover, the marketing and logistics levels have different goals. In addition, at the logistical level, the goals of individual elements are also different. Further, our marketing subsystem of the enterprise has a goal that differs from the goals of similar systems at the marketing level. Thus, on the first and on the second levels we have network systems, where our management system interacts with other marketing systems and with their reflection at the logistical level.

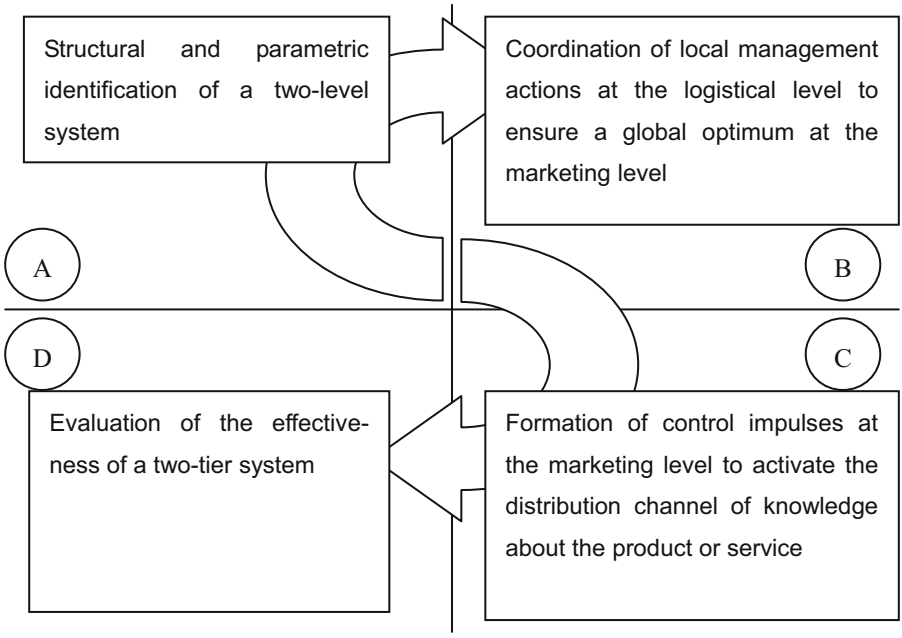


**Fig. 2.** Task tree of business process of virtual promotion of a product

Therefore, our future technology must form a management system based on the company's existing marketing service on the Internet. In other words, it is necessary to form a network of management systems at the marketing level and a network of management facilities at the logistics level (Fig. 2).

Thus, the first main task is the structural-parametric identification of two channels (levels) [10–14].

The next task is to coordinate the two levels. Since the goals of the first and second level systems may be different, we will talk about different types of coordination.

1. Coordination of the problem to be solved in the subsystem of the marketing level. In this case, for some selected control influence, as a result of solving the top-level problem, each subsystem of the logistics level will have such local control influences, in which the criterion of the top-level problem reaches its global optimum.
2. Coordination of tasks to be solved in each of the subsystems of the two-level system. For this variant of coordination, the local control actions of the lower-level tasks provide a global optimum in the upper-level task.
3. Coordination on the compromise value of the objective functions of the subsystems of the two-level system. This situation is typical in the presence of conflict both between subsystems of one level and between subsystems of different levels. If the conflict is not antagonistic in nature, then the choice of control influence is reduced to decision-making on many criteria of individual subsystems.

Our coordination task has the second type, when the global result is provided by control actions on performance of tasks at logistic level.

## 3 Proposed Approach

The next task is to form control actions from the marketing level to the logistics level, when there are three main types of such actions at the second level: consolidation (loading), processing and scattering of knowledge. The main issue in solving this problem (Fig. 3) is to determine the form of knowledge about the product that should be accumulated and processed at the distribution level. In the literature on search engine optimization on the Internet [5–9] the term semantic kernel of web content is most often used. Therefore, we will call the form of presentation of knowledge about a product or service that must be loaded into the logistics network of the second level - the semantic kernel.

The semantic kernel is not a static object, but can change over time. This change needs to be tracked.

The last task (Fig. 2) is to determine the optimization criteria for assessing the effectiveness of a two-tier system (marketing and logistics of knowledge about the product). This criterion will determine the quality of virtual promotion of goods at the enterprise level.

Thus, the paper will consider the methodology of virtual promotion of goods or services through the solution of four main tasks:

1. Structural and parametric synthesis of the marketing channel of virtual promotion as a two-level system. The first level is the management system. It generates control signals and analyzes the effectiveness of the second level - the level of distribution of knowledge about the product or service. Thus, the first task is to generate input and output signals in the channel, build a channel model, determine the criteria for channel efficiency, propose algorithms for identifying elements of a two-tier system and choose criteria and methods for verifying the channel model.

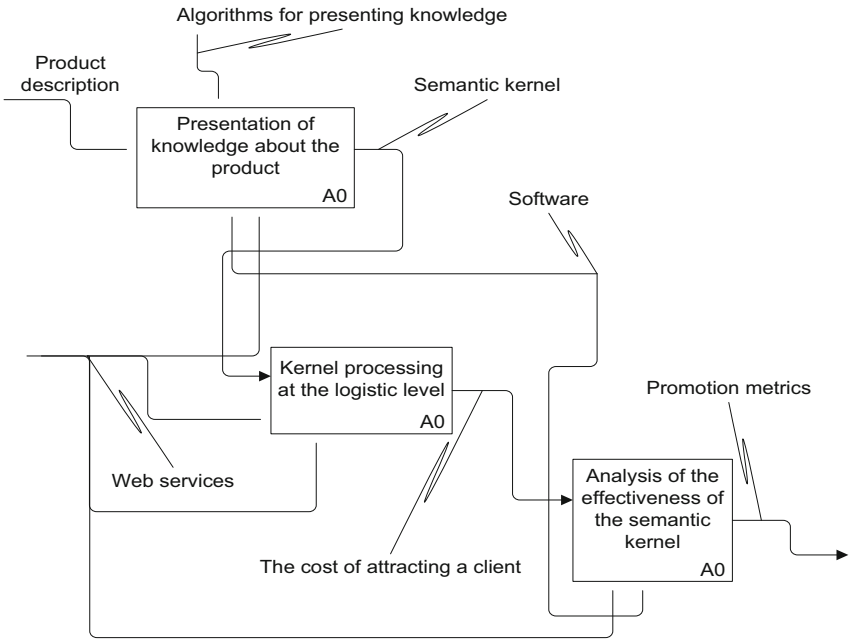


**Fig. 3.** New schema of business process of virtual promotion of a product

2. Coordination of the functioning of the knowledge distribution channel in order to achieve a given level of efficiency of the channel as a whole. Solving this problem means the formation of control signals for the logistics channel in order to provide a global optimum criterion for the effectiveness of the marketing channel of virtual promotion.
3. Formation of the semantic kernel of web content as a control impulse for the logistics level of the marketing channel. The semantic core is a message that is formed in the channel in order to encourage a potential customer to buy a given product or service.
4. Verification of the constructed two-level system consists in the confirmed efficiency of the offered model.

According to the classical definition, the purpose of product promotion is to increase the efficiency of sales, sales and demand [15, 16]. However, the essence of promotion is any form of communication that is used to inform potential customers about the product, packaging, brand, advertising exhibitions, demonstrations, business and more. Then the effectiveness of sales depends on the effectiveness of the message about the product to a potential customer. That is, the effectiveness of promotion is determined by the effectiveness of the communication channel between the company and customers.

There are two types of communication channels: personal and impersonal. Virtual promotion has a second type.

Conceptually, promotion can be represented in the form of four stages:

1) Defining the goals of promotion.
2) Defining the target audience.
3) Choice of promotion tools.
4) Determining the promotion budget.

On the other hand, sales efficiency is determined by the concept of profitability of sales. This is a percentage of the share of profit from each earned hryvnia. Or it is the ratio of net income to the amount received from the sale of products, which is expressed as a percentage [15, 16]. Then the impact of promotion is determined by the costs that the company makes on the formation of the communication channel and the message itself. Profitability can also be affected by the number of customers involved through the message and the communication channel.

Thus, you should determine the metrics and criteria that describe the effectiveness of the channel and the message. On the one hand, we need criteria that indicate the reduction of costs for the formation of the communication and communication channel, and on the other hand, we need metrics that determine the number of customers involved through the channel and communication.

The message includes the following information for the potential customer:

1) Description of the product or service and its characteristics.
2) Place of receipt of goods or method of delivery.
3) Information about the packaging of the goods.
4) Justification of the price of the goods.
5) Payment procedure.

Currently, the main indicator that can describe the effectiveness of the channel and the message on the Internet will be traffic [6, 7]. This metric describes the number of unique users who read messages on the channel per unit time.

Channels are also becoming more typical. There are the following types of channels where a message about a product or service is placed on the Internet: search engine promotion, contextual advertising, banner advertising and social media marketing. Each channel is characterized by the budget and the traffic it generates. Thus, you can enter the conditional efficiency of the channel and the message based on the classical theory of marketing [15] and search engine optimization [17–20]:

$$E = \frac{T^2}{B} \tag{1}$$

where T – traffic, B – budget of a channel.

$$P = \frac{B}{T} \tag{2}$$

where P – the price of attracting one customer of goods through this channel.

A modern communication channel must meet four conditions: uniqueness, urgency, specificity and usefulness.

The message should be formed from the standpoint of content marketing [17–20]. That is, the so-called "ladies" must be formed.

The classic indicator of channel efficiency is the rate of return on investment in the communication channel [17]:

$$ROI = \frac{\Pr - Ex}{Ex} \tag{3}$$

where Pr – profit, Ex- expenses on channel formation.

Another important indicator is the conversion (4). It reflects the achievement of the main goal - to attract the required number of buyers of goods.

$$K = \frac{Q}{N} \tag{4}$$

where Q – the number of customers attracted by the promotion channel, and N is the total number of channel visitors [18].

All of the above indicators correspond to one of seven categories, namely: traffic, bounce rate, conversion, the cost of attracting one buyer, the average check, return on investment, repeat visits. But these indicators are only metrics, unfortunately, the criterion of effectiveness among them is not identified. Modern theory of Internet promotion is based only on the metric approach.

Thus, there is an urgent problem of formulating a criterion for the effectiveness of virtual promotion. This criterion should describe the benefit of the message in the promotion channel and the benefit of the channel itself. And since virtual promotion is a two-tier system, the benefits must be determined at two levels coordinated in time.

## 4 Summary and Conclusion

The above description of a new control object - virtual promotion of a product allows us to formulate the following conclusions:

1) The main goal of managing this object is to increase the sales of the product.
2) The object of management is complex and includes two channels: logistics and marketing. The first channel performs the function of distributing knowledge from node to node, and the second channel controls this transformation. The logistics channel forms the configuration of the system, and the marketing channel forms its organizational structure.
3) The article presents a modern diagram of the business process of virtual promotion within the framework of the IDEF0 methodology. The study of this scheme allowed us to form a set of four tasks. This is a new approach, a new vision of the problem of virtual promotion of a product.
4) The approach proposed in the article is based on solving the problem of structural-parametric synthesis, the problem of coordinating the functioning of two channels, the problem of forming a semantic kernel, as well as the problem of evaluating efficiency based on a new criterion of optimality.

5) The analysis of metrics for evaluating the effectiveness of virtual promotion was carried out and it was revealed that there is no criterion of optimality.

The direction of further research should be considered the problem of forming a criterion for the optimality of virtual promotion. This criterion should include constraints and metrics for the seven identified areas.

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# Conditions of Non-uniform Fluidization in an Auto-oscillating Mode

Bogdan Korniyenko(✉), Yaroslav Kornienko, Serhii Haidai, Andrii Liubeka, and Serhii Huliienko

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**Abstract.** The use of fluidization technique provides high efficiency in diffusion-controlled processes. However, the efficiency and intensity of the application of the fluidization technique significantly depends on the hydrodynamic mode of fluidization and the height of the bed of solid granular material. To solve this problem in this work is proposed to apply non-uniform fluidization in an auto-oscillating mode at a height of the bed of solid material, which is four times higher than the breakdown height of the gas jet. In this work is presented the physical model of non-uniform jet-pulsating fluidization in an auto-oscillating mode at the ratio of the height of the initial bed of solid granular material to the breakdown height of the gas jet $z_f/H_0 = 0.33$ and $z_f/H_0 \leq 0.25$. The influence of the rate of supplying of the gas liquefying agent on the quality of hydrodynamics as well as on the formation of the gas bubble is analyzed. The conditions under which the absence of stagnant zones on the working surfaces of the gas distribution device is ensured, which is very important when supplying the coolant with a temperature exceeding the melting point of components of the granular material which are sensitive to temperature.

**Keywords:** Granulation · Fluidized bed · Non-uniform fluidization

## 1 Introduction

The use of fluidization techniques in heat and mass transfer processes ensures their implementation with a heat utilization rate of more than 50% [1–11]. This is especially important when carrying out granulation processes of liquid systems in a fluidized bed.

The economic feasibility of such processes is achieved through the use of a coolant with a high temperature, however, there is a risk of formation of stagnant zones with subsequent melting of the material on the working surfaces of the gas distribution device (GDD) [12–20].

The rate of transfer processes in dispersed media in the presence of a phase transition is determined by the thickness of the diffusion sublayer.

In order to further increase the efficiency of diffusion-controlled processes in recent years in published works [12–20] it is proposed to use non-uniform fluidization in an


Z. Hu et al. (Eds.): ISEM 2021, LNNS 463, pp. 14–27, 2022.
https://doi.org/10.1007/978-3-031-03877-8_2

auto-oscillating mode. As a result of the implementation of such a hydrodynamic mode of fluidization, it is possible to slightly reduce the thickness of the diffusion sublayer located near the surface of solid particles and, accordingly, to increase the intensity of the transfer processes.

Typically, a mechanical device (pulsator) was used for pulsating coolant supply [21]. However, with this method of supplying the heated coolant there is a cyclic temporary cessation of its supply. There is a certain time interval when the granular material is stationary on the surface of the gas distribution device (GDD). In the case of dehydration and granulation processes in the presence of materials which are sensitive to temperature, this method of implementing inhomogeneous fluidization is unacceptable.

The essence of the technical solution to eliminate this shortcoming is to create a hydrodynamic regime, which provides active volumetric circulation of granular material in the layer with minimizing the volume and residence time of the granules on the working heated surfaces of the gas distribution device (GDD) having a high temperature [22–48].

## 2 Physical Model of Non-uniform Jet-Pulsating Fluidization in an Auto-oscillating Mode

A method of implementing non-uniform fluidization in an auto-oscillating mode without the use of a mechanical pulsator was investigated in works [12–20].

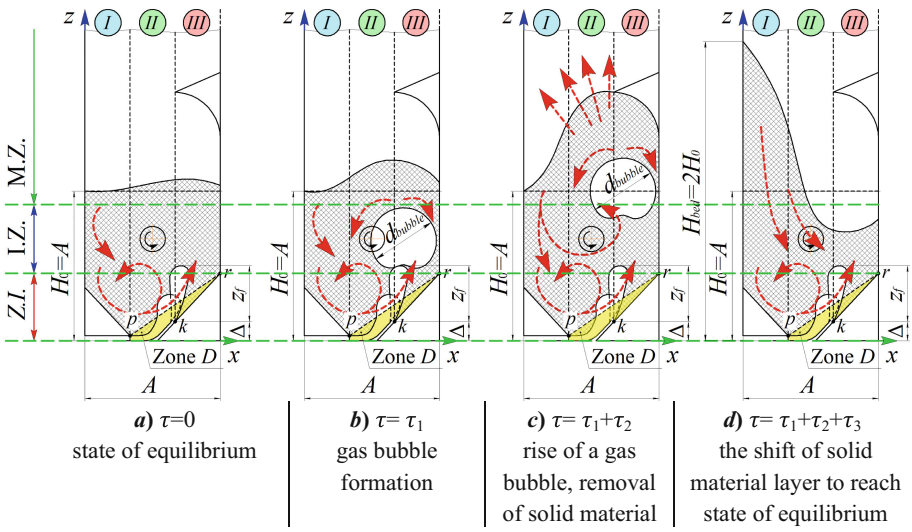



**Fig. 1.** Physical model of non-uniform jet-pulsating fluidization in an auto-oscillating mode at $H_0/A = 1$; $z_f/H_0 = 0.33$; *Z.I.* – zone of intensive heat and mass transfer; I.Z. – irrigation zone; M.Z. – the movement zone of granular material

The auto-oscillating non-uniform jet-pulsation mode of fluidization, Fig. 1, a detailed description of which is given by the authors [15–20] is provided by two-level asymmetric

introduction of the liquefying agent into the granulator chamber and takes place in several stages:

1 – gas bubble formation – $\tau_1$, Fig. 1 a, b;
2 – inertial ejection of granular material from zones *II* and *III* into the space upper the bed of solids and its redirection to the relaxation zone *I* – $\tau_2$, Fig. 1 c;
3 – intensive movement of granular material from zone *I* to the formed cavities in zones *II* and *III* with the return of the bed of solids to equilibrium – $\tau_3$, Fig. 1 d.

The total duration of the cycle of one pulsation, s:

$$\tau_{cycle} = \tau_1 + \tau_2 + \tau_3. \tag{1}$$

The proposed model of non-uniform fluidization allows to realize three-dimensional mixing of granules (solid particles) in the apparatus with passage through all technological zones, providing active renewal of the contact surface of the phases, which is confirmed by research results in [12–20] at the height of the fixed bed of solid material $H_0/A \approx 1$.

## 3 Determination of Main Parameters of the Non-uniform Jet-Pulsating Fluidization in an Auto-oscillating Mode

### 3.1 Determination the Speed of Movement of the Mass Center of Bed of Solids

The conditional scheme of movement of the center of mass of the bed of granular material is shown in the Fig. 2.

In the general case, the motion of the mass center is complex, so it is proposed to determine the chord between the initial $A_0$ and extreme upper position of the center of mass at point $A_{\max}$. The deviation of the position of the center of mass along the $z$ and $x$ axes was determined by the values of $\Delta z$ and $\Delta x$.

It is assumed that the movement of mass center along the axis $y$ is absent and $\Delta y = 0$ m. With this in mind, the length of the segment $A_0A_{\max}$ can be determined from the expression, m:

$$|A_0A_{\max}| = \sqrt{\Delta z_i^2 + \Delta x_i^2}. \tag{2}$$

The average speed of movement of mass center of bed of solids can be defined as, m/s:

$$w_{\text{mass center}}(\tau_i) = \frac{\sqrt{\Delta z_i^2 + \Delta x_i^2}}{\Delta \tau_i}. \tag{3}$$

With this at the beginning of the pulsation cycle at $\tau_i = 0$ s the bed of solid granular material is in state of equilibrium, its mass center occupies the initial position $A_0(z_0; x_0)$, Fig. 2, and the value of average speed of its movement is $w_{\text{mass center}} = 0$ m/s.

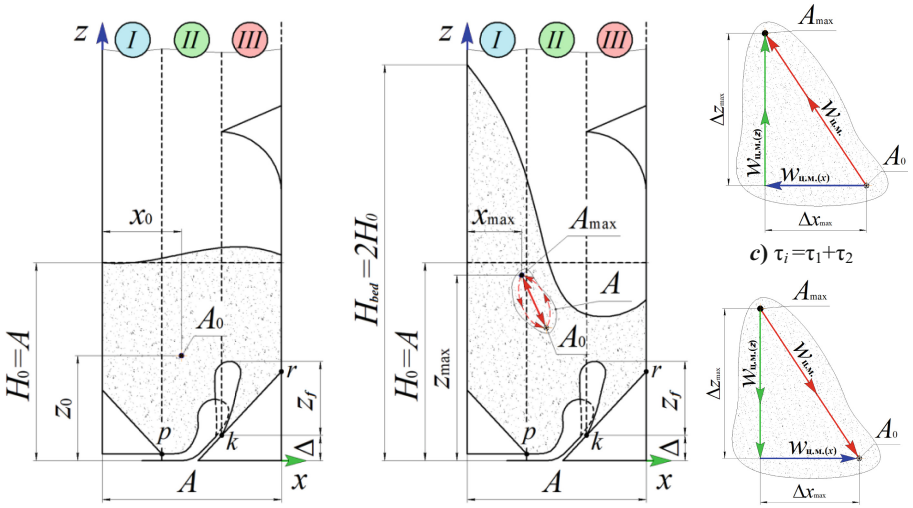



**Fig. 2.** Conditional scheme of movement of mass center of solid material bed at realization of non-uniform jet-pulsating fluidization in an auto-oscillating mode in the case when $H_{0(1)}/A = 1$

According to the physical model, the maximum value of the displacement of the mass center at point $A_{\max}$ is achieved during the second stage of the pulsation ($\tau_1 + \tau_2$), and the return at point $A_0$ in the third stage ($\tau_3$). Then the speed of movement of the mass center from $A_0$ to $A_{\max}$ ($w_{\text{mass center}(\uparrow)}$) and, accordingly, in the opposite direction from $A_{\max}$ to $A_0$ ($w_{\text{mass center}(\downarrow)}$) can be defined as, m/s:

$$w_{\text{mass center}(\uparrow)} = \frac{\sqrt{\Delta z_{\max}^2 + \Delta x_{\max}^2}}{\tau_1 + \tau_2}. \tag{4}$$

$$w_{\text{mass center}(\downarrow)} = \frac{\sqrt{\Delta z_{\max}^2 + \Delta x_{\max}^2}}{\tau_3}. \tag{5}$$

The average value of the speed at the extreme positions of the mass center of bed of solids for stage 3 can also be written as, m/s:

$$w_{\text{mass center}(\downarrow)} = \sqrt{2g\,\Delta z_{\max}}. \tag{6}$$

The value of the speed of movement of the mass center to the point $A_{\max}$ is derived from the expression:

$$\frac{w_{\text{mass center}(\uparrow)}}{w_{\text{mass center}(\downarrow)}} = \frac{\tau_1 + \tau_2}{\tau_3} = K_{\text{m.c.}}. \tag{7}$$

Whence:

$$w_{\text{mass center}(\uparrow)} = w_{\text{mass center}(\downarrow)} K_{\text{m.c.}}. \tag{8}$$

where $K_{\text{m.c.}} < 1$, and values of $\tau_1$, $\tau_2$ and $\tau_3$ are determined experimentally.

### 3.2 Determination of the Hydrodynamics Quality

Thus, the hydrostatic pressure at point $p$, Fig. 3, which is determined by the height of the bed of solid granular material in zone I will increase 2 times compared to the initial state at $\tau = 0$ when $H_{bed} = H_0$, Fig. 1 a. That is, at this point in zone $D$, Fig. 3, there may be a stationary zone or low moving speed of solid granular material on the working surface of the gas distribution device with size $\delta$.

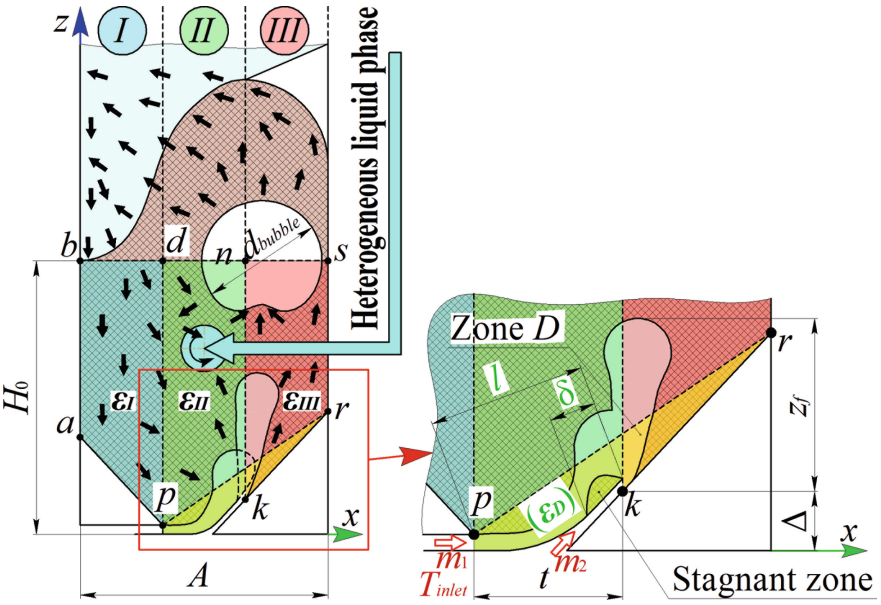



**Fig. 3.** Scheme for determining the quality of the mode of fluidization

To do this, the dependence of the porosity in the specified zone $D$ – $\varepsilon_{D(i)} = f(\tau)$ was determined by video recording and compared with the allowable set point $[\varepsilon_D] = 0.85\ldots0.95$.

To quantify the quality of hydrodynamics, the Taguti method is used, which allows to calculate the loss of quality of hydrodynamics [18–20]:

$$L_D = K_1\left([\varepsilon_D] - \varepsilon_{D(i)}\right)^2 + K_2\left(\frac{[\delta] - \delta_{(i)}}{l}\right)^2, \tag{9}$$

where $K_1 = 0.3$ and $K_2 = 0.7$ – are the coefficients of proportionality; $\varepsilon_{D(i)}$ – experimentally determined the current value of porosity in zone $D$; $[\delta] = 0.01l$, m; $l$ – chord length of GDD plate, m.

Hydrodynamics quality index [18–20]:

$$Y_a = 1 - L_D. \tag{10}$$

The area of satisfactory quality is achieved when the value of the quality index of hydrodynamics is $0.9 \le Y_a \le 1$. The maximum value of the quality of hydrodynamics

$Y_a = 1$ will be achieved when the value of the loss of quality $L_D \to 0$ [18–20]. The final satisfactory value of the quality of hydrodynamics will be determined experimentally.

### 3.3 Determining the Conditions for Ensuring High-Quality Hydrodynamic Mode of Fluidization

The technical concept of the slit-type gas distribution device is that such a kinetic energy can be locally introduced into the bed of solid granular material, which with a frequency $f = 1.5\ldots 2$ Hz would increase the potential energy of the fluidized bed by almost 2 times.

Energy consumption to increase the potential energy of the fluidized bed:

$$E_p = \frac{\Delta M_{bed}}{\tau_1 + \tau_2}(H_0 + \Delta h_I)g. \tag{11}$$

With this the condition $E_k > E_p$ must be fulfilled:

$$E_k = \frac{(m_1 + m_2)w_{slits}^2}{2}. \tag{12}$$

where $m_1 + m_2$ – the total mass consumption of the liquefying agent, kg/s; $w_{slits}$ – gas velocity in the slits of gas distribution device, m/s (assume that $w_{slits} = w_{slit(1)} = w_{slit(2)}$).

Ensuring conditions for the quality of hydrodynamics in zone *D*, Fig. 3, is achieved solely by the influence of gas velocity in the slits, which depends on the coefficient of GDD cross section – $\varphi$.

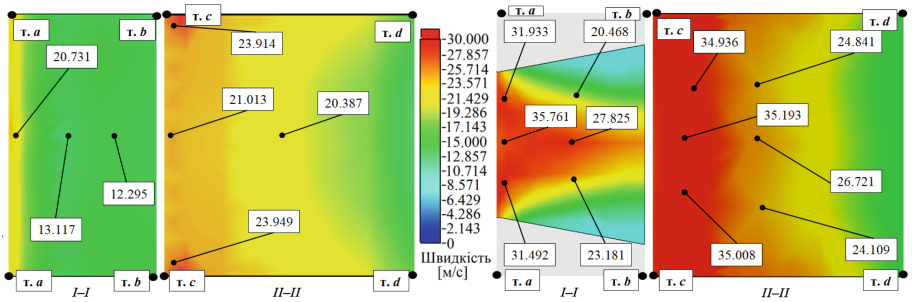
$$w_{slit(1)} = \frac{V_s}{\varphi AB}, \tag{13}$$

where $V_s$ – the total volumetric liquefying agent consumption at the given temperature calculated from the mass transfer conditions, $m^3/s$; *A*, *B* – geometric dimensions of the device in cross section of GDD, m; $\varphi$ – coefficient of GDD cross section, %.

### 3.4 Flow Simulation in SolidWorks

For the slit-type gas distributing device with different values of the cross section coefficient [22–24] For the slit-type gas distributing device with different values of the cross section coefficient [22–24] using the SolidWorks plots of the velocities of the gas coolant near the working surfaces of gas distributing device (GDD) were obtained, Fig. 4 *a*, *b*.

The obtained simulation results confirm that when using a gas distribution device of type 2 with a cross-section coefficient $\varphi_2 = 4.9\%$ the value of the gas velocity at the exit from the slit of the GDD is 1.72 times higher than when using GDD of type 1.




***a)*** GDD type 1($\varphi_1$=6%) ***b)*** GDD type 2 ($\varphi_2$=4.9%)

**Fig. 4.** Diagrams of liquefying agent velocities for two types of GDD at $V_s = 0.03736$ m$^3$/s (*SolidWorks*)

### 3.5 Explanation of Determining the Gas Velocity in Slits of GDD

The presence of a local increase in gas velocity by 1.8 times at the outlet of slit 1 of the gas distribution device (GDD) type 2 allowed to increase the kinetic energy of the jet by 3.24 times, which meets the requirements of the physical model to the gas distribution device.

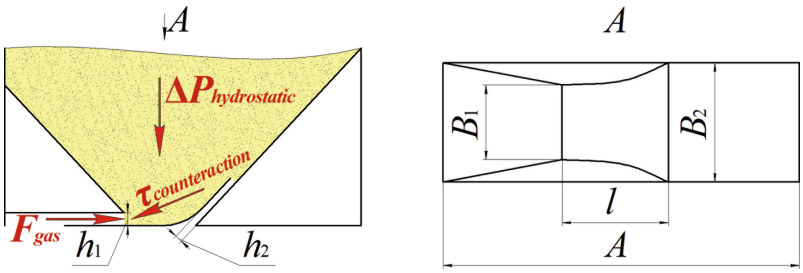



**Fig. 5.** Scheme of force distribution in the area of introduction of the liquefying agent

To ensure the quality index of hydrodynamics Ya $\geq$ 0.9, the velocity in the slit of the gas distribution device at the level of the point $p$ must be $w_{slits} \geq 35$ m/s, Fig. 5.

The force of hydrodynamic pressure of the gas $F_{gas}$ must be greater than the total counteraction force $\tau_{counteraction}$ on the surface of GDD arising from hydrostatic pressure:

$$F_{gas} \geq \tau_{\text{counteraction}} \tag{14}$$

$$F_{gas} = \Delta P_{gas} f_{slits}, \tag{15}$$

where $\Delta P_{gas}$ – gas pressure at point $p$, Pa:

$$\Delta P_{gas} = \rho_{gas} w_{slits}^2 \Big/ 2, \tag{16}$$

where $f_{slits}$ – the area of the slit at point $p$, $m^2$:

$$f_{slits} = h_1 B_1, \tag{17}$$

where $h_1$ and $B_1$ – height and width of the slit at point $p$, m.

$\tau_{counteraction}$ – the total force of counteraction, N:

$$\tau_{\text{counteraction}} = \Delta P_{hydrostatic} K_\tau f_{GDD}, \tag{18}$$

where $\Delta P_{hydrostatic}$ – hydrostatic pressure of the layer of granular material at point $p$, Pa:

$$\Delta P_{hydrostatic} = H_0(1 - \varepsilon_0)\rho_{solids} g, \tag{19}$$

where

$\varepsilon_0$ – porosity (proportion of voids) of a tightly packed bed of solids ($\varepsilon_0 = 0.4$);

$\rho_{solids}$ – density of solid granules, $\rho_{solids} = 1450$ kg/m$^3$;

$g$ – acceleration of gravity, $g = 9.81$ m/s$^2$;

$K_\tau$ – transformation coefficient;

$h_1$ and $B_1$ – height and width of the slit at point $p$;

$f_{GDD}$ – the working surface area of the gas distribution device (trapezoids with bases $B_1$ and $B_2$ and height $l$), $m^2$:

$$f_{GDD} = \frac{B_1 + B_2}{2} l. \tag{20}$$

Then after substitution (15) and (18) into (14):

$$\Delta P_{gas} f_{slits} = \Delta P_{hydrostatic} K_\tau f_{GDD}. \tag{21}$$

For the case $H_0 = 0.32$ m the transformation coefficient is determined by the expression:

$$K_\tau = \frac{\Delta P_{gas} f_{slits}}{\Delta P_{hydrostatic} f_{GDD}}. \tag{22}$$

For all other cases, it is possible to calculate the gas velocity in the slits, which provides an index of hydrodynamic quality $Y_a \geq 0.9$ by expression:

$$w_{slits} = \left( \frac{2H_0^*(1 - \varepsilon_0)\rho_{solids} g f_{GDD} K_\tau}{\rho_{gas} f_{slits}} \right)^{0.5}, \tag{23}$$

where $H_0{}^*$ – the given value of the total height of fixed bed of solids, m.