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УТВЕРЖДАЮ

Директор

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ПРОГРАММА КАНДИДАТСКОГО ЭКЗАМЕНА
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2.6.13. Процессы и аппараты химических технологий

(код и наименование научной специальности)

Программа кандидатского экзамена рассмотрена и одобрена на заседании Ученого совета ИПХЭТ СО РАН, протокол от 31.05.2024 № 7.

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Введение

Настоящая программа кандидатского экзамена разработана для научной специальности 2.6.13 Процессы и аппараты химических технологий в соответствии с Положением о перечне кандидатских экзаменов, процедуре сдачи кандидатских экзаменов и прикреплении лиц для сдачи кандидатских экзаменов, утвержденном приказом от 19.12.2022 № 15365-484.

Кандидатский экзамен представляет собой форму оценки степени подготовленности соискателя ученой степени кандидата наук к проведению научных исследований по конкретной научной специальности и отрасли науки, по которой подготавливается или подготовлена диссертация.

Соискатель ученой степени кандидата наук должен показать высокий уровень сформированности знаний, умений и навыков самостоятельного поиска, анализа и переработки зарубежной литературы по тематике диссертационного исследования; способности к выступлению с докладами на иностранном языке и участию в международных конференциях, школах-семинарах.

Процедура проведения кандидатского экзамена

Кандидатский экзамен проводится в форме сочетания устной и письменной форм.

Кандидатский экзамен по иностранному языку проводится в два этапа:

1) аспирант выполняет письменный перевод научного текста по специальности на русский язык. Объем текста – 5000 печатных знаков; время выполнения работы – 45–60 минут. Успешное выполнение письменного перевода является условием допуска ко второму этапу экзамена;

2) аспирант выполняет три задания (устно):

- изучающее чтение оригинального текста по специальности (объем текста: 2500–3000 печатных знаков; время выполнения работы – 45–60 минут; передача извлеченной информации осуществляется на русском языке);
- беглое чтение оригинального текста по специальности (объем текста – 1000–1500 печатных знаков; время выполнения – 2–3 минуты); для проверки беглого чтения допускается использовать текст первого этапа кандидатского экзамена;
- беседа с экзаменаторами на иностранном языке по вопросам, связанным со специальностью и научной работой аспиранта.

Качество перевода, выполненного аспирантом в рамках первого этапа кандидатского экзамена, оценивается по зачетной системе. Перевод должен быть представлен в виде рукописного текста.

Перечень заданий для кандидатского экзамена (промежуточного контроля)

Первый этап экзамена – образец текста для письменного перевода представлен в Приложении 1.

Критерии оценки первого этапа экзамена:

- *«зачтено»* – выполнен весь объем перевода, отобранные языковые средства соответствуют поставленной задаче, наблюдается оправданное, последовательное и логичное изложение мысли, отсутствие повторов и нарушения стилевого единства текста, вариативность используемых лексико-синтаксических единиц; отсутствуют грубые грамматические, орфографические и лексические ошибки в языковом материале;

- «*не зачтено*» – выполнен не весь объем перевода, имеются грамматические, орфографические и лексические ошибки в языковом материале, перевод выполнен неадекватно.

Задания **второго этапа экзамена** оцениваются по четырехбалльной шкале: «*отлично*», «*хорошо*», «*удовлетворительно*», «*неудовлетворительно*».

Второй этап экзамена – образец текста для изучающего чтения представлен в Приложении 2.

Критерии оценки текста для изучающего чтения:

- «*отлично*» – представлен полный перевод, адекватный смысловому содержанию текста на русском языке. Текст грамматически корректен, лексические единицы и синтаксические структуры, характерные для научного стиля речи, переведены адекватно;
- «*хорошо*» – представлен полный перевод, но встречаются лексические, грамматические и стилистические неточности, которые не препятствуют общему пониманию текста, однако не согласуются с нормами языка перевода и стилем научного изложения;
- «*удовлетворительно*» – фрагмент текста переведен не полностью или с большим количеством лексических, грамматических и стилистических ошибок, которые препятствуют общему пониманию текста;
- «*неудовлетворительно*» – представлен неполный перевод; аспирант демонстрирует непонимание содержания текста, большое количество смысловых и грамматических ошибок.

Второй этап экзамена – образец текста для беглого чтения представлен в Приложении 3.

Критерии оценки текста для беглого чтения:

- «*отлично*» – чтение корректное, лексические единицы и синтаксические структуры, характерные для научного стиля речи, прочитаны правильно;
- «*хорошо*» – встречаются неточности в произношении, которые не препятствуют общему пониманию текста;
- «*удовлетворительно*» – фрагмент текста, предложенного на экзамене, прочитан с большим количеством ошибок, которые препятствуют общему пониманию текста;
- «*неудовлетворительно*» – абсолютно неверное прочтение текста, большое количество ошибок в произношении.

Второй этап экзамена – перечень вопросов для беседы с экзаменаторами на иностранном языке по вопросам, связанным с научной специальностью и научной работой аспиранта:

1. When did you first think of becoming a scientist?
2. Why did you decide to enter the post-graduate courses?
3. Do members of your family have science degrees?
4. Who is your research advisor?
5. What is the subject of your research?
6. Is the topic of your research connected with your graduate work?
7. What is the motive force of scientific progress?
8. Can science do without theories and hypotheses?
9. Do you think you could make a discovery?
10. Could you describe the present state of research in your sphere?
11. What latest discoveries in your field of research do you know?
12. What characteristics should a scientist have nowadays? Why do you think so?
13. What scientists in your field of research do you know?
14. Who do you think is the founder in your field of research?
15. Did you take part in any international conferences in English?

16. How often are international conferences held in your field?

17. Have you got any published articles?

18. Are you satisfied with your level of English?

19. Do you think it is important for a scientist to communicate in English? Why do you think so?

20. Do you think it is important for a scientist to translate English texts?

Критерии оценки беседы с экзаменаторами на иностранном языке по вопросам, связанным с научной специальностью и научной работой аспиранта:

- «*отлично*» – аспирант способен вести беседу на иностранном языке, не допустил существенных ошибок в построении предложений, правильно употребил видовременные формы глагола;

- «*хорошо*» – аспирант в целом способен вести беседу на иностранном языке, аспирант допустил не значительные ошибки в построении предложений либо в употреблении видовременных форм глагола;

- «*удовлетворительно*» – ведение беседы вызывает у аспиранта существенные затруднения, допустил ошибки в построении предложений либо в употреблении видовременных форм глагола;

- «неудовлетворительно» – аспирант не способен вести беседу на иностранном языке, ответы не соответствуют лексико-грамматическим нормам иностранного языка.

Итоговая оценка по кандидатскому экзамену выводится как средняя оценка членов комиссии за задания второго этапа экзамена.

Конкретные задания к кандидатскому экзамену подбираются преподавателем в соответствии с тематикой научных исследований аспиранта.

Кандидатский экзамен проводится в смешанной форме: задание первого этапа кандидатского экзамена выполняется письменно, задания второго этапа – устно. Для подготовки соискатель использует экзаменационные листы.

Рекомендуемая литература

Основная литература:

1. Басова, О.В. Английский язык для аспирантов и соискателей естественно-научных специальностей: учебное пособие / О.В. Басова, О.С. Дворжец. – Омск: Омский государственный университет им. Ф.М. Достоевского (ОмГУ), 2019. – 138 с. – Режим доступа: по подписке. – URL: https://biblioclub.ru/index.php?page=book&id=613822 (дата обращения: 19.02.2024).

2. Основы перевода, аннотирования и реферирования научно-технического текста: учебное пособие / Е.А. Чигирин, Т.Ю. Чигирина, Я.А. Ковалевская, Е.В. Козыренко; науч. ред. Е.А. Чигирин. – Воронеж : Воронежский государственный университет инженерных технологий, 2019. – 157 с. – Режим доступа: по подписке. – URL: https://biblioclub.ru/index.php?page=book&id=601568 (дата обращения: 19.02.2024).

3. Стрельцов, А.А. Практикум по переводу научно-технических текстов: English ↔ Russian / А.А. Стрельцов. – Москва ; Вологда: Инфра-Инженерия, 2019. – 381 с. – Режим доступа: по подписке. – URL: https://biblioclub.ru/index.php?page=book&id=564673 (дата обращения: 19.02.2024).

Дополнительная литература:

1. Данилова, С.В. Английский язык для академических целей=Academic Listening and Watching: учебное пособие по развитию навыков аудирования для магистрантов естественно-научных дисциплин / С.В. Данилова. – Омск: Омский государственный университет им. Ф.М. Достоевского (ОмГУ), 2019. – 90 с. – Режим доступа: по подписке. – URL: https://biblioclub.ru/index.php?page=book&id=613819 (дата обращения: 19.02.2024).

2. Кисель, Л.Н. Английский язык. Интенсивный курс обучения чтению=English. Intensive Reading Training Course: учебное пособие / Л.Н. Кисель, Д.Г. Панасюк. – Минск: РИПО, 2021. – 108 с. – Режим доступа: по подписке. – URL: https://biblioclub.ru/index.php?page=book&id=697398 (дата обращения: 19.02.2024).

3. Тихонов, А.А. Английский язык: теория и практика перевода: учебное пособие / А.А. Тихонов. – Москва : ФЛИНТА, 2019. – 120 с. – Режим доступа: по подписке. – URL: https://biblioclub.ru/index.php?page=book&id=611202 (дата обращения: 19.02.2024). – ISBN 978-5-9765-4143-6.

4. Фролова, В.П. Век химии=Age of Chemistry (English for students of chemical direction): английский язык для студентов химического профиля: учебное пособие / В.П. Фролова, Л.В. Кожанова, Т.Ю. Чигирина ; науч. ред. Е.А. Чигирин. – 3-е изд., перераб. и доп. – Воронеж: Воронежский государственный университет инженерных технологий, 2019. – 201 с. – Режим доступа: по подписке. – URL: https://biblioclub.ru/index.php?page=book&id=601455 (дата обращения: 19.02.2024).

5. Чигина, Н.В. Деловое общение на иностранном языке: учебное пособие / Н.В. Чигина, Е.Г. Бухвалова, С.В. Сырескина; Самарский государственный аграрный университет. – Кинель: Самарский государственный аграрный университет, 2020. – 113 с. – Режим доступа: по подписке. – URL: https://biblioclub.ru/index.php?page=book&id=611425 (дата обращения: 19.02.2024).

Приложение 1
(обязательное)

Образец текста для письменного перевода

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Local and global process intensification

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ABSTRACT

The present paper aims at proposing a complementary view of process intensification (PI) based on the concepts of local intensification and global intensification. Local intensification is defined here as the classical approach of PI based on the use of techniques and methods for the drastic improvement of the efficiency of a single unit or device. Some examples are given to illustrate that local process intensification presents several limitations when compared to holistic overall process-based intensification, named global intensification. Indeed, when PI focuses on single units (reactors, separators, hybrid separators, etc.), the strong interactions among all units within the process are ignored and the impact of local intensification of a single unit can be very limited, resulting in weak improvement of the whole process. This paper identifies that process intensification is broader than technical improvement of devices or processes and has to consider several drivers such as economics, safety, eco-efficiency and sustainability to fulfill the key objectives in designing new plants and retrofitting existing units.

1. Introduction

Process intensification (PI), formally regarded as process improvement strategy, consists, according to Stankiewicz and Moulijn [1], in novel equipment, processing techniques, and process development methods that, compared to conventional ones, offer substantial improvements in (bio) chemical manufacturing and processing. It is related to new and innovative technologies which replace large expensive and energy-intensive equipment by devices which are smaller, less costly and more efficient [2–4]. Among the different strategies, a well-established approach is the design of multifunctional devices, which merge several unit operations, e.g. reaction and separation into one apparatus [2]. However, recent approaches in PI predominantly focus on equipment and more specifically on microstructured technologies, providing a high surface-to-volume ratio, hence increasing mass and heat transfer by several orders of magnitude [5]. The revolution-like manners in which microtechnology develops (and as which it is sometimes praised) manifest themselves in the vast number of patents in this field of research. Every year, numerous patents are reported for microtechnology-related areas. Focusing on microreactors, more than 1500 patent publications in different fields of chemical applications already exist, annually rising in number by more than 250 new patents [6]. Then, from the numerous studies published in the literature, it is clear that PI focuses on the equipment improvement, which can be defined as a local approach of process improvement strategy.

On the other hand, process system engineering (PSE), according to Grossmann and Westerberg [7], aims at improving decision-making for the creation and operation of the chemical supply chain, which deals with the discovery, design, manufacturing, and distribution of chemical products. From this definition, PSE can be considered as a global approach of process improvement strategy. Recently, Moulijn et al. [8] felt that it was timely to attempt to better define the place of PI in relation with other chemical engineering disciplines, such as PSE. Based on the preliminary approach by Grossmann and Westerberg [7] and Marquardt et al. [9], they proposed to define PI in conjunction with PSE. The focus and action of PSE take place along the product creation chain, as a top-down approach from the enterprise to the molecules, while the focus and action of PI are on chemical engineering aspects of the process units separately. PI has a more creative than integrating character and primarily aims at higher efficiency of individual steps in that chain, for instance by offering new mechanisms, materials, and structural building blocks for process synthesis.

In addition, the scales considered are different; PSE focuses less on the scale of molecules, sites and (nano-) structure, whereas PI

Abbreviations: API, active pharmaceutical ingredient; CSTR, continuous stirred tank reactor; GHG, greenhouse gases; LCA, life cycle assessment; PI, process intensification; PFR, plug flow reactor; PR, process retrofit; PSE, process system engineering; ROI, return on investment time; RSR, reactor separator recycle.

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explicitly includes this level but often pays less attention to the highest levels. It is clear that PI has consequences for the "longitudinal" action of PSE; for instance, development and application of a reactive separation can influence the PSE over the whole chain, from molecule to site, if not to enterprise.

The improvement of processes must also be examined in the context that a major portion of the chemical industry has matured. Most chemical plants were built at a time when profit margins could be kept large and thus were not typically designed to be the most efficient from an energy and raw material perspective. Nowadays, competitive pressures have greatly increased the need for more efficient processes claiming for the redesign and the modernization of existing facilities. Grossmann et al. [10] estimated that, in the end of the 80s, 70–80% of all process design projects in the western countries dealt with the redesign, i.e. retrofit design of existing facilities.

Also, the successful commercialization of specialty chemicals requires the ability to redesign processes quickly, to respond to changes in new technology and to the short life cycle of new products. According to Grossmann and Westerberg, the development of retrofit design strategies is a more difficult problem than the design of new processes because it includes a far greater number of alternatives than the grassroots problem, due to the need to evaluate and use existing equipment. The nature of the retrofit problem is by nature complex and multidimensional. They propose a list of technical objectives as the increase of the throughput by debottlenecking and by higher conversion of feedstocks, the processing of a new feedstock and the improvement of the quality of the product. Sustainability is also considered by the increase of process safety, the reduction of the environmental impact of an existing process, the reduction of energy input per unit of production, and the higher operability of the process (flexibility, controllability).

Concerning economics and the major constraints of process retrofit (PR), several approaches can be developed. The change of the operating conditions of the process can enable to keep the same implemented equipment which is obviously the least costly in terms of investment. The change of architecture of the process by changing the piping that connects the devices is another alternative. For example, with respect to the cost of purchasing a new column, repiping typically incurs very modest costs. It is also possible to keep the process flowsheet intact but to change the equipment sizing, sometimes in ways that the external physical dimensions of the equipment are not altered. Such changes could include installation of new tube bundles inside existing heat-exchanger shells, closer packed trays or even packing inside columns. And finally, the last approach is the addition of new equipment to reach the objectives.

From the definition proposed by Grossmann et al. [10], it is obvious that PR shares numerous keywords (improvement of conversion and yield, reduction of energy consumption and environmental impact, safety considerations, etc.) with process system engineering and process intensification. This large overlapping between those three concepts shows also that PR is concerned by local and global intensification and that synergies between them may exist.

However, as stated by El-Halwagi and co-workers [11], there are some limitations in most of the previous works focused on unit-based intensification when compared to holistic overall process-based intensification.

El-Halwagi and co-workers identified process integration as a holistic and systematic framework for intensification where, however, process intensification has a broader scope. They defined two main classes for intensification: single-unit intensification and plant intensification. Unit intensification refers to the previous definition of process intensification. On the other hand, plant intensification focuses on the improvement of the global process: maximize the throughput, minimize inventory, or minimize utility materials and feedstock. In case of plant intensification, units that will be intensified are not pre-specified and more than one unit can be intensified simultaneously.

The present paper aims at proposing a complementary view of process intensification based on the concepts of local intensification and global intensification. Local intensification is defined here as the classical approach of PI based on the use of techniques and methods for the drastic improvement of the efficiency of a single unit or device (reactors, separators, mixers, exchangers, etc.), to overcome specific limitations that can be related to thermodynamics, kinetics, heat or mass transfer and energy supply. It mainly focuses on the technical improvement of the performances of equipment but the interactions among all units within the process are ignored and the impact of intensifying a single unit on the rest of the process is not considered.

First, global (or overall) intensification has a more general view on the whole process, considering first a multi-dimensional approach consisting in the simultaneous improvement of several units. The process is improved by inventory and utility minimization and by throughput maximization. Process intensification is achieved using the classical methods of local intensification and heat and mass integrations meaning that a complex flowsheet or architecture should be designed to increase the overall process efficiency. The impact of a local change will have an effect on the entire process due to the strong interactions between units and should therefore be studied at the whole process scale.

Secondly, global intensification possesses a multi-dimensional aspect where different drivers (economic, safety, eco-efficiency and sustainability) are included in the strategy. There are some limitations in most of the previous PI works as they focused mainly on technical drivers but did not develop an holistic view, omitting to include the different drivers. This is not the case with retrofit design that recently included various methods to evaluate and reduce the environmental impact of chemical processes. Sun et al. [12] proposed the formulation of a multi-objective optimization problem to determine sustainable chemical process designs taking into account economic, environmental and societal aspects. El-Halwagi and co-workers [13] presented a multi-objective optimization procedure for the recycle and reuse networks including the environmental implications of the discharged wastes using life-cycle assessment. More recently, they developed [11] a first attempt to couple an intensification strategy with a multi-objective optimization problem, but the mathematical functions used to represent intensification lacked for realism. In a recent study, Gani and co-workers [14] presented the development of a software tool and its application to chemical processes, based on the implementation of an extended systematic methodology for sustainable process design.

Further work is still needed to combine process retrofit, process intensification and process system engineering to define an intensification strategy which takes into account both the local approach of PI and the global approach of PSE considering the whole process by multi-objective optimization to propose sustainable and intensive chemical process designs. The strategy should answer the following questions. Which equipment should be intensified in a process? What is the impact of local process intensification of a device on the overall process performance? How should new process architecture be achieved? Which optimization criteria should be chosen? What are the criteria of safer processes?

In the present paper, some examples will be given to illustrate that the classical approach of process intensification based on single-unit intensification presents several limitations when compared to holistic overall process-based intensification.

Приложение 2
(обязательное)

Образец текста для изучающего чтения

4

Crystallization with Compressed Gases

E. Reverchon, H. Kröber, U. Teipel

4.1
Introduction

Many product properties that are of relevance in industrial use can be adjusted by changing the particle size and particle size distribution of the powder. This statement is valid in several fields, ranging from polymers to pharmaceutical and inorganic powders.

In the case of solid explosives and propellants, small particles are as a rule required to improve the combustion process. Indeed, the attainment of the highest energy from the detonation of a solid explosive depends strongly on the particle size of the material.

Grinding and crystallization from solutions are largely used as micronization processes in industry and have been described in previous chapters. However, these processes suffer from some limitations: it is difficult to control the particle size and particle size distribution of powders, especially when very small (micron-sized) particles are required. Liquid crystallization also suffers from the problem of solvent contamination of the precipitate (crystal inclusions) and jet milling is not suitable for the treatment of shock-sensitive substances.

As an alternative to the traditional techniques, various supercritical-fluid based precipitation processes have recently been proposed. These techniques can potentially overcome all the previously described limitations of the classical micronization processes. Supercritical fluids are compressed gases that are used at temperatures and pressures higher than their critical point. At the critical point, the liquid-gas phase boundary disappears and the surface tension approaches zero. Near the critical point, even small increases in the applied pressure cause a sharp increase in the density and, correspondingly, the dissolving capacity of the supercritical fluid. Supercritical fluids exhibit properties that are a combination of liquid and gas-like characteristics (Table 4.1). The density of compressed gases is in the same range as that of organic liquids, while the viscosity is close to that of gases. Because their diffusion coefficient is larger than that of liquids, supercritical fluids have enhanced mass transfer properties, making them especially suitable for extraction operations,

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Table 4.1. Comparison of some physical data between gases, liquids and compressed gases.

	ϱ (kg/m^3)	η (10^3 Pa s)	D (m^2/s)
Gas at 0.1 MPa:			
ϑ = 25 °C	0.6–2.0	0.01–0.03	$(1–4) \times 10^{-5}$
Supercritical fluids:			
T_c, p_c	200–500	0.01–0.03	7×10^{-8}
T_c, 4 × p_c	400–900	0.03–0.06	2×10^{-8}
Liquids:			
at ϑ = 25 °C	600–1600	0.2–3.0	$(0.2–2) \times 10^{-9}$

particularly in the foodstuffs industry. As a result of these special physical properties, solid particles can be processed by supercritical fluid technologies. Supercritical fluids, in principle, do not give problems of solvent contamination because when decompression occurs, they are completely released from the solute.

The supercritical fluid of election is CO_2 since it has relatively low critical parameters (ϑ_c = 31.1 °C and p_c = 7.38 MPa), it is not toxic, non flammable and cheap. The operating conditions for supercritical fluids processing are generally mild, thus giving no problem to process 'sensitive' materials. Also, the control of the particle size and particle size distribution of the micronized material promises to be relatively simple to obtain by continuously modulating the process conditions.

Various supercritical fluid-based precipitation processes have been proposed. Jung and Perrut summarized the experimental and theoretical work on these techniques and gave an overview of substances which were processed by these processes [4.1]. In the following part of this chapter we will discuss their major characteristics.

4.2 Rapid Expansion of Supercritical Solutions

The first micronization process based on supercritical fluids that has been proposed is the Rapid Expansion of Supercritical Solutions (RESS) [4.2–4.4]. In this process, the solvent power of the supercritical fluid is used to dissolve the compound to be micronized by fluxing the supercritical fluid in a fixed bed formed by the particles of the starting material. Then, the solution formed is depressurized down to atmospheric pressure in an atomization nozzle. The fast expansion of the supercritical solution reduces the solvent power of the fluid to nearly zero and the solute precipitates in the expansion chamber. A schematic flow sheet of a typical experimental setup is shown in Fig. 4.1. A more detailed description of the experimental setups used can be found in the literature [4.5–4.7].

Using this technique, it is possible to obtain very high supersaturation ratios that can result in the production of very small particles. Some studies on the RESS process were devoted to the identification of the process parameters that control the

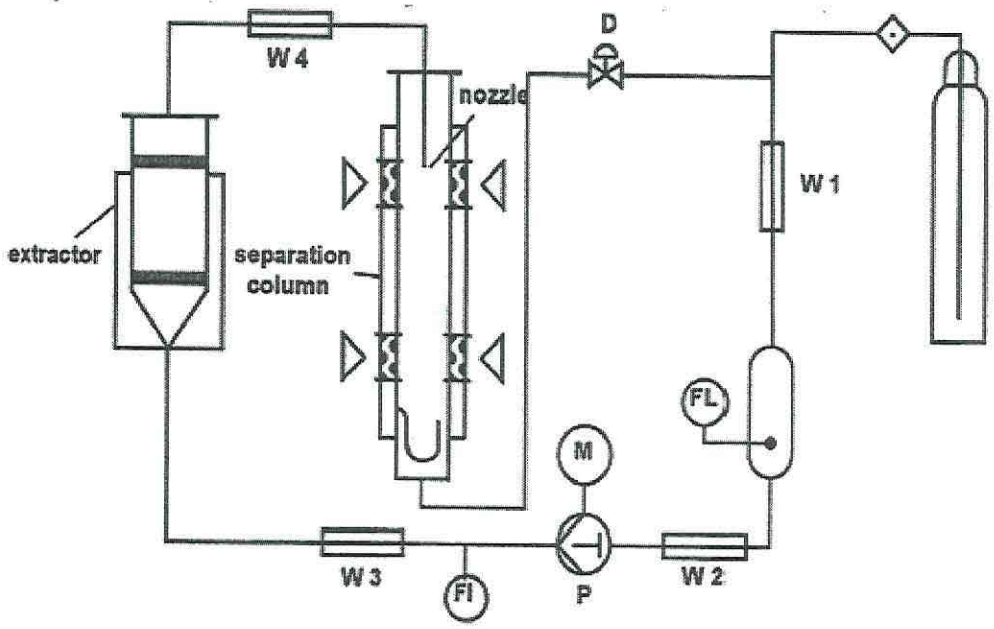

Figure 4.1. Flow sheet of the experimental setup: W, heat exchanger; P, membrane pump; FI, mass flow meter; FL, liquid CO_2 reservoir; D, pressure control.

precipitation of particles [4.4]. The main parameters that control the RESS process are pre-expansion temperature and pressure and expansion chamber temperature and pressure.

It is difficult to propose a systematic description of the investigated substances and morphologies obtained by RESS since a large variety of particle shapes and sizes have been observed and very different experimental arrangements have been used. Moreover, many different substances were investigated (organic and inorganic materials, polymers and biopolymers and biodegradable materials) which differed in their physical and chemical properties so that a comparison is difficult. Kröber *et al.* micronized benzoic acid and cholesterol as model substances for pharmaceuticals under different process conditions [4.8]. In contrast to the experimental work of other groups, their investigations were carried out with nozzles up to three-times larger than normally used so that an industrial application was simulated more realistically. The first theoretical descriptions demonstrate the complexity of the process, but only provide a rough, qualitative interpretation of experimental results. Türk showed the calculated temperature, pressure and supersaturation profiles as a function of capillary length for various experimental conditions [4.6].

Приложение 3
(обязательное)

Образец текста для беглого чтения

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Investigation of power characteristics in a novel cup-shaped-blade mixer

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ABSTRACT

The impeller performance and energy utilization are closely related to the agitator design. In this article, the power characteristics of the novel cup-shaped-blade (CB) impellers were investigated by using the Newtonian fluid in a stirrer tank, considering the effects of shape parameters, angle of the blades, baffles, agitator speed and physical properties of working fluid. An accurate power correlation for the CB impellers was established. In addition, the CFD method was employed to simulate the power consumption and flow characteristics, and the calculated power value fitted well with the experimental value. The obtained results could provide the basis for the design and scale-up of the CB impellers.

1. Introduction

Mixing in stirrer tanks plays an important role in various industries processes in the field of food, agrichemicals, cosmetics and beverage industries etc [1]. The agitator is a key part in the mixing vessel which directly determines power characteristics and the mixing performance of the mixing system. It is widely recognized that the power consumption is one of fundamental design parameters [2–4]. In recent years, a lot of work has been done on the power consumption for different liquids using various agitators, adopting both experimental and simulated techniques to carry the research on power characteristics. It is desirable to design a new type agitator blade to fulfill the requirements of different situations, besides the applications of existing agitators in multi-combination modes.

The modification of agitators has been reported recently. For example, Roman et al. [5–7] studied the characteristics including power consumption, complete suspension speed and gas-liquid transfer efficiency of a modified blade Rushton turbine in different systems. They found that the modified blade turbine was more efficient than the standard turbine. Niedzielska et al. [8] investigated the power consumption of a ribbon impeller with particular design and found that the geometrical parameters had a significant impact on power consumption and efficiency of agitator. On the other hand, for the high viscosity system, with the first report by Schneider et al. [9], intensive researches on the coaxial mixer were reported by the Canadian Tanguy's group [10–15]. According to different mixed materials and working conditions, they designed and studied a series of new multiple impellers. In their research, the proximity impellers (helical ribbon, anchor) and dispersing turbines pitched blade turbine (PBT), rushton turbine (RT) were used together. The power consumption and mixing performance of coaxial mixers were mainly studied. The results showed that these multiple impellers exhibited excellent mixing performance in many specific situations. At present, there are few studies on novel agitators which have a simple structure but extensive applications. So far no report has been found on the type of cup-shaped-blade (CB) impellers.

Computational fluid dynamics (CFD) has been widely adopted to understand deeply the power consumption, flow field and the turbulent kinetic energy in the stirred tank [16–20], with the precision increased gradually. Thus, the objective of this paper is to study the power characteristics of the novel CB impellers, in combination with the CFD numerical simulation to predict the power consumption and flow patterns. Experimental and simulation methods are performed considering the different parameters, such as impeller geometry (impeller type and blade angle), agitation condition (impeller speed and power) and process condition (working fluid concentration).

2. Experimental materials and methods

2.1. Experimental setup

The experiments were carried out in a pilot-scale transparent tank made from plexiglas equipped with flat bottom, with the agitators mounted centrally. The mixer and the detailed geometrical dimensions are shown in Fig. 1. In the experiments, the liquid height H_L is equal to the tank diameter T and corresponding to a liquid volume of 0.4 m^3. The distance C of CB impellers is $T/4$ whereas that value of PBT and RT

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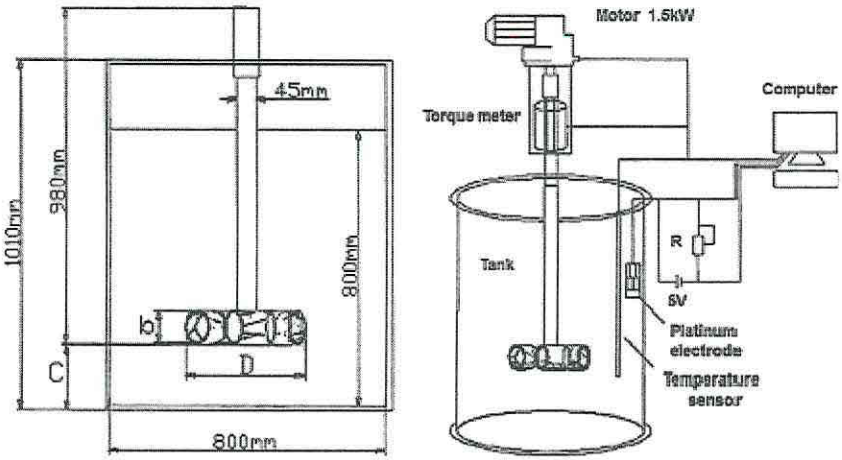

Fig. 1. Schematic diagram of the experimental setup.

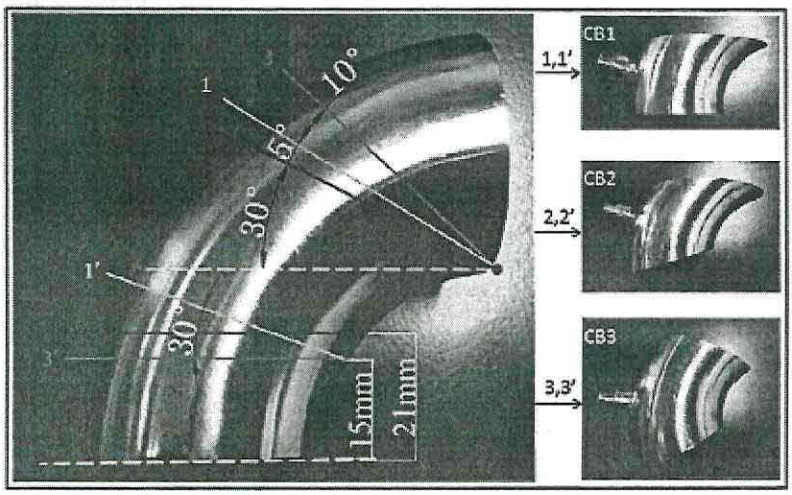

Fig. 2. Schematic diagram of the cup-shaped blades.

is *T/3*. The four removable baffles are *T/10* long, 5 mm thick, 83 cm high and can be installed into the tank every 90°.

Fig. 2 showed the schematic diagram of cup-shaped blades production and blades that were cut by the 90° stainless steel elbow with an inner diameter of 56 mm. Three types of the cup-shaped-blades (CB1, CB2, CB3) provided by FLUKO (China) were studied. The CB impellers consist of three cup-shaped blades and the angles of blades can be adjusted flexibly. Another two widely used impellers PBT and RT were also investigated as comparisons. The impellers and detailed geometrical dimensions are shown in Fig. 3 and Table 1.

2.2. Materials

Malt syrup (70–100 wt%) was employed as the Newtonian fluid, of which the viscosity could be adjusted by adding the pure water [21,22]. The rheological properties of malt syrup were determined by rotational viscometer (Brookfield DV-C). The density of the Newtonian fluids is between 1000 and 1450 kg/m^3, and the viscosity ranges from 0.001 to 4.56 Pa·s. The measurements as well as experiments were performed at 29 ± 1 °C. Table 2 lists the specific experiment conditions.

2.3. Methods

The power number is a reliable design specification in the mixing operation and has been widely used to predict the process results, following the first report of power consumption on 1934. Recently, Chapple et al. [4] studied the power consumption of PBT, RT through accurate torque measurement techniques and performed the generic power number curves. Liu et al. [22] studied the power consumption of a double inner impeller and the power curves under different conditions. Tanguy et al. [10] studied the power consumption of the blade-helical ribbon impellers at different speeds and performed a generalized power curve.

To determine the power consumption, the motor has been coupled to the torque sensor and the power could be calculated from the torque. The net power consumption can be obtained by the following formula