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RECYCLING AND REUSE OF ORGANIC SOLVENTS FROM WASTE PAINTS

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Waste paints and other expired or unused coatings can be recycled before disposal. This is important because it reduces the volume of landfill waste and allows a certain amount of components to be reused. This contributes not only to waste reduction but also to improved environmental sustainability, while significant economic savings are realized.
This paper presents the design of a paint recycling device that works on the principle of distillation. In contrast to classical distillers, which work on the principle of distillation with a heat exchanger condenser, the proposed system consists of a main tank and a distillation column. The advantages of this device are that fractions with similar evaporation temperatures can be separated more easily.
A mathematical model based on thermodynamic and process parameters was developed to predict the behavior of the distillation process for different solvents. Based on the real parameters of the process, such as working pressure, composition, and flow rate of the feed mixture, evaporation temperature, etc., the time, composition, quality, and quantity required for the separation of each component were calculated, which represents the economic justification of this process. Three solvents with different compositions were tested using adjustable parameters of the distillation process, and the results provided insights into the distillation behavior, the characteristics of the recycled mixture, and the quality and yield of the recovered products.

Keywords: Paints, Recycling, Distillation, Mathematical Modeling, Optimization

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INTRODUCTION

Paints and various coatings are used in almost every household as an integral part of regular maintenance. They are also commonly found in everyday applications and across multiple industries, including construction, automotive, shipbuilding, catering, marketing, and others [1,2].

Paints and other organic solvent-based agents that have reached their expiry date, suffered wear and tear, have damaged packaging, or are otherwise no longer usable should be recycled and reused instead of being disposed of directly in landfills or incinerators. These materials can be considered liquid waste containing small amounts (up to maximum of 10%) of non-volatile impurities [3].

Assessing the feasibility of recycling chemical solvents involves calculations based on the type, quantity, and composition of the organic solvent. The results indicate which component can be recovered and how much the volume of solid waste deposited is reduced [2,4].

Waste and unused stocks of paints and other organic solvents pose a significant environmental challenge both locally and globally, as they are classified as hazardous waste [5]. As a result, many waste management organizations are actively working to address this issue. A global trend in recent years has been to encourage consumers to accurately calculate the amount of paint needed for work, thereby minimizing leftover quantities. Effective paint waste disposal is crucial and involves efforts to recycle and minimize the quantity of waste that requires treatment. Additionally, appropriate systems for the disposal of paint waste in landfills should be made available, depending largely on the quantity or volume of waste generated [1].

Paints often contain chemicals such as solvents and heavy metals that can contaminate soil and groundwater, posing risks to both the environment and human health. Recycling unused paint reduces these negative impacts and lowers the costs associated with hazardous waste disposal [4-6].

Several paint recycling associations have been established in Australia, primarily initiated by the paint industry and transporters, covering approximately 95% of all building and decorative paints sold in the country [7]. In addition to ensuring the responsible disposal of paint waste, these organizations are also committed to researching new methods for repurposing or replacing unused paint materials [3]. In the United States, numerous non-profit organizations have been created to represent paint manufacturers in the planning and management of paint recycling programs [8]. Since 2009, one of these organizations has set up 1,765 paint collection points, most of which are located in grocery shops and supermarkets. Their goal is to ensure that as much leftover paint as possible is either recycled or otherwise put to beneficial use [9].

In Canada, the paint and coatings industry operates the world's most extensive post-consumer paint recycling program, with activity in each province. In 2017, 28 million kilograms of used paint were collected and recycled enough to repaint approximately 560,000 average-sized houses [10]. Unused or leftover paint remains an important target of waste management efforts, as it constitutes a significant amount (volume) of household hazardous waste. The associated management costs are high, but there is great potential for waste reduction (volume), refreshment, recycling, and reuse [1,2].

In Serbia, legislation requires all users to store used paints, varnishes, and solvents in appropriately organized facilities that meet fire safety regulations. Several organizations in Serbia are responsible for the packaging, transport, and further treatment of this type of waste. These organizations ensure that such waste is properly stored, transported, and finally disposed of by incineration in accredited facilities abroad. Certain financial resources must be allocated for this service, which largely depends on the quantity (volume) of hazardous waste. If some of the used paints were recycled and reused, the amount of waste sent for incineration and the disposal costs could be significantly reduced [5,11,12].

A semi-batch incineration plant is commonly used for the recycling of paints and organic solvents [3,13]. The design of this plant consists of a conical stainless steel distillation vessel (boiler) equipped with a heating jacket. The solvent is rapidly heated via a double jacket transfer. The setup is based on a chemical solvent recycling device consisting of a main tank with a mixer heated by a jacket and a column with trays used for a more selective separation of the components.

To evaluate the efficiency of solvent recovery, a mathematical model was developed based on simulations of a distiller with a tray column. This model can be used to optimize the separation/purification of organic solvents under environmentally friendly process conditions. The model takes into account all the parameters of the real process, the input data related to the organic solvent being recycled, providing optimized parameters as final information. Recovery rates ranging from 95% to 99.9% can be achieved, depending on the composition of the solvent mixture [2,4,5].

The distillation process

The distillation process is described using a developed mathematical model.

A schematic representation of the paint recycling device is shown in Figure 1. The device consists of a main vessel with a stirrer, heated by hot oil or steam via a jacket, and connected to a column with trays and a condenser. The process operates in a semi-batch mode, where the feed mixture is continuously introduced into the system as long as a constant liquid level is maintained in the vessel. The condensed volatile components are collected in a receiving tank. The advantage of the proposed device compared to a classical distillation unit with a standard heat exchanger (condenser) lies in its ability to achieve a higher purity of the recovered components. Based on the described technological process for the treatment of organic solvents using a specially designed device, a mathematical model was developed to simulate the operation of the unit with various organic solvents [4,5].

The feed mixture is heated under continuous stirring. Separation occurs due to differences in boiling temperatures of the components, with the aid of a distillation column to enhance selectivity. The collected data is used for process simulation and optimisation [2].

The components of the system are labeled in Figure 1 as follows: 1 - solvent collecting tank, 2 - distillation column, 3 - residue collecting tank, P1 - batch pump, V1 - inlet valve, V2 - outlet valve, HE - heat exchanger, LS - level indicator, TI - temperature indicator, S1-S8 – flow indicators for process streams.

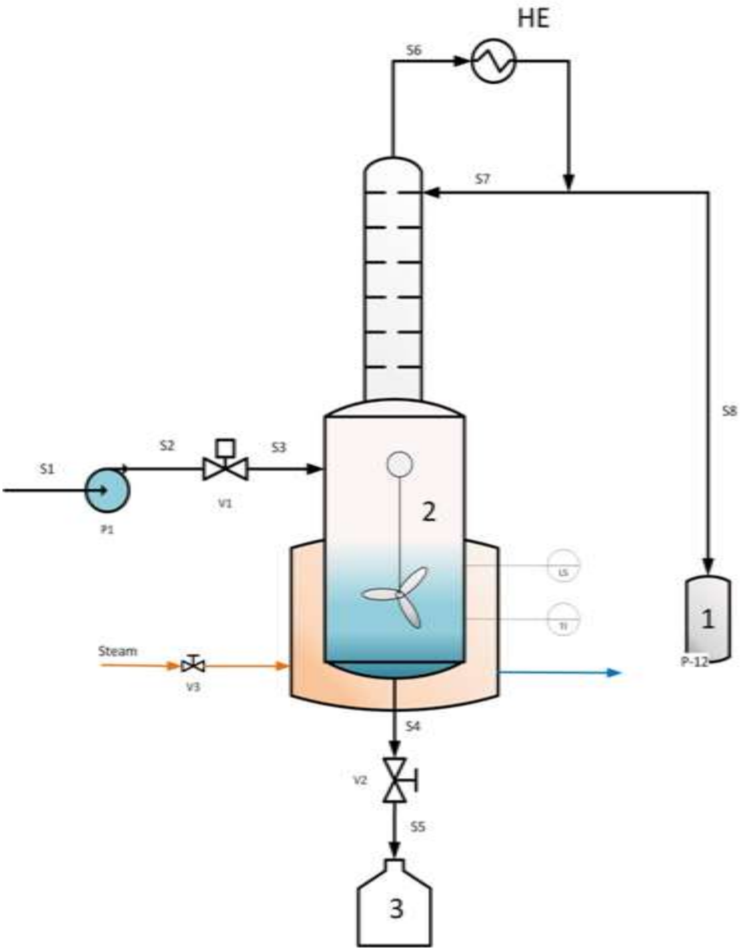

Figure 1. Schematic diagram of the paint recycling system

At the beginning of the process, the distillation apparatus (2) is charged with a recycled solvent-insert mixture (S1). Valve V2 is closed, and the unit is filled by activating pump P1 and opening valve V1. Filling stops once the liquid reaches the LS level sensor. The pump P1 and valve V1 are then deactivated. The operating pressure is set by turning on the vacuum pump. Once the system is fully charged, the distillation begins [12].
The mixer is started, and heating is activated. The temperature of the heating oil should be maintained between 30 and 60 °C above the boiling temperature of the solvent to achieve sufficient driving force for the vaporization. During the distillation process, a recycled mixture is constantly fed in. As the mixture evaporates, it is condensed by a coolant flowing through the condenser. The distillation continues until the temperature of the mixture in the main vessel reaches approximately 10 °C above the boiling point of the pure solvent. The condensed vapor (stream S8) is collected in vessel 1 [12,13].

The distillation process is terminated by closing the valve V1 on the feed line of the solvent S2, by switching off the heater, by switching off the vacuum pump, and the system is allowed to cool to ambient temperature. The valve for the condenser's cooling fluid is also closed.
The non-volatile residue (the sludge) is discharged through valve V2 into the collection container 3 and then packed and sent for disposal by authorized personnel. It should be noted that in real industrial settings, the plant cleaning stage is very important, and begins half an hour after distillation, allowing the residue to cool and preventing unwanted vapor emissions. Before discharging, it is essential to check that atmospheric pressure has been established and the vacuum has been completely released [5,13].
The distiller with mixer is heated by the oil jacket, while the gas phases obtained in the column are routed to the condenser. The volatile components are condensed and collected in the distillate vessel. The recycling solvent mixture is continuously heated and mixed, and the components are separated due to the different evaporation temperatures. The vacuum pump establishes the desired working pressure [13].

The distillation process can be divided into eight separate, consecutive parts:
1) Charging the system with inert gas,
2) Introducing the mixture for the process of distillation,
3) Establishing a vacuum in the system and starting the gas phase cooling system,
4) Heating the recycling mixture to the boiling point,
5) Distillation process,
6) Cooling of the mixture,
7) Compression of the system to atmospheric pressure by introducing inert gas,
8) Discharging the residue into storage containers [4,12].

All these separate processes are interconnected and form a complete recycling process.

1) Charging the system with inert gas. This process is very important to increase the safety of the distillation process, as organic solvents are flammable. Nitrogen is used as an inert gas [4].

2) After charging the system with inert gas, the recycling mixture is introduced up to the maximum fill level.

3) Decompression of the system and establishment of a cooling system. The operating pressure is built up by switching on the vacuum pump. The operating conditions for the condensation of the vapor phase are established by draining cooling water via the condenser. After building up the vacuum, the cooling system is switched on [13].

4) The recycling mixture is heated to a boiling point above the jacket with warm oil. The duration of the process depends on the composition of the batch to be recycled and is determined by the following equations, where all variables are defined in the Nomenclature:

$$M\frac{dh(T,P,x)}{dt}=Q \tag{1}$$

$$Q=UA\left(\overline{T}_{oil}-T\right) \tag{2}$$

$$Q=\dot{m}_{oil}\cdot c_{P,\mathrm{oil}}\left(T_{oil,\mathrm{inlet}}-T_{oil,\mathrm{outlet}}\right) \tag{3}$$

$$h=h(T,P,x) \tag{4}$$

Depending on the composition of the feed mixture, the enthalpy of the batch is determined using the thermodynamic models of Peng-Robinson or the NRTL [2,5].

5) After reaching the boiling temperature, the solvent evaporates and condenses in the condenser and flows off into the collecting tank. A fresh mixture is continuously fed into the vessel, ensuring that the mixture volume is constant. This is achieved by a negative feedback control system (Figure 1) [4].

The distillation process is described by the following system of differential-algebraic equations [2,4]:

$$\frac{dM}{dt}=\dot{m}_i-\dot{m}_o \tag{5}$$

$$\frac{dM_s}{dt}=\dot{m}_i x_u^s \tag{6}$$

$$\frac{dM_r}{dt}=\dot{m}_i x_u^r-\dot{m}_o y_u^r \tag{7}$$

$$\frac{dE}{dt}=\dot{m}_i h_i-\dot{m}_o h_o+Q \tag{8}$$

$$Q=UA\left(\overline{T}_{oil}-T\right) \tag{9}$$

$$Q=m_{oil}\cdot c_{P,oil}\left(T_{oil,inlet}-T_{oil,outlet}\right) \tag{10}$$

$$K_r=K(P,T,x,y) \tag{11}$$

$$h_i=h(P,T,x_i) \tag{12}$$

$$h_o=h(P,T,y_o) \tag{13}$$

$$h=h(P,T,x) \tag{14}$$

$$\rho=\rho(x,P,T) \tag{15}$$

$$E=M\cdot h \tag{16}$$

$$M=\rho(x,P,T)\cdot V \tag{17}$$

The heating oil temperature is maintained at 30-60 °C above the solvent boiling point. During the distillation process, a mixture for recycling is continuously introduced. Distillation continues until the temperature of the mixture in the main vessel reaches a value 10-20 °C above the boiling point of the pure solvent. The distillation process is completed by closing the valve on the feed line for the solvent that is recycled in the distiller, whereupon the heaters and the vacuum pump are switched off [12].

6) The mixture is cooled via the oil jacket system until the ambient temperature is reached. Finally, the valve for the liquid supply to the condenser is closed. The duration of the cooling process depends on the properties of the residue and is determined by the following equations [5,13]:

$$M\frac{dh(T,P,x)}{dt}=-Q \tag{18}$$

$$Q=UA\left(T-\bar{T}_{oil}\right) \tag{19}$$

$$Q=m_{oil}\cdot c_{P,oil}\left(T_{oil,inlet}-T_{oil,outlet}\right) \tag{20}$$

$$h=h(T,P,x) \tag{21}$$

7) The system is compressed to atmospheric pressure by introducing inert gas [4].

8) Emptying the residue into the disposal container. The sludge that remains at the bottom of the distiller vessel is emptied into the collection container via a valve and then packaged by the responsible parties and made available for transport. It should be noted that in the real system, the cleaning stage of the plant is very important, which in practice begins half an hour after distillation in order to cool the precipitate and prevent unwanted evaporation. Before starting emptying, it is necessary to check that atmospheric pressure has been established, i.e., that the vacuum in the system has been completely released [4,13].

Based on the described technological process of treating organic solvents, data were obtained for simulation and process optimization. Using appropriate mathematical models, experimental measurements were analyzed and calculations for organic solvent recovery were carried out. Based on the input and output data, an algorithm was developed to optimize the recycling of the individual organic solvent components and simultaneously minimize the volume of the waste sludge. In order to dispose of the waste sludge as economically as possible and to reuse the recycled components, a mathematical model was developed to provide insight into the justification of the recycling process for various organic solvents in advance [2,4,5].

RESULTS AND DISCUSSION

The distillation tests performed on three different solvent mixtures (Solvents 1-3) under reduced pressure (0.5 bar) revealed clear trends in terms of solvent behavior, separation efficiency, and potential for recycling or safe disposal. During the distillation process, the level in vessel 2 is kept constant using two parameters: the control of valve 1 and the temperature control in vessel 2. Despite the differences in composition, the distillation system showed comparable thermal and dynamic profiles, demonstrating the effectiveness of the method used for the recovery of solvents in paint recycling and treatment units. The parameters of the distillation process are listed in Table 1.

Table 1: Parameters of the distillation process

	Distillation process parameters		
	Solvent 1	Solvent 2	Solvent 3
Boiling temperature at 0.5 bar, [°C]	70	40.5	79.3
Heating fluid operating temperature, [°C]	115	95.5	124.3
Solvent temperature at which the distillation process is interrupted, [°C]	80	57	89.3

For all three solvents, a progressive increase in temperature and a corresponding decrease in solvent concentration in vessel 2 were observed as distillation progressed. This is due to the gradual removal of more volatile components and the concentration of suspended solids and higher-boiling fractions.

Solvent 1 was recycled in a distillation system, and the results of the calculations are shown in Table 2. Solvent 1 is a complex mixture with the following composition: 26-48% toluene, 10-23% acetone, 13-26% ethyl acetate, 10-24% methyl acetate, 3-9% methanol, 3-9% THF, 3-11% ethanol, 1-2% cyclohexane, 1-2% propanol, 1-3% butanol and 1-3% butyl acetate with a wide boiling range, which has a steady vapor flow of about 47-55 kg/h after the initial heating phase and stabilizes after about 10 hours. The working temperature increased from 49-70 °C during distillation, with the solvent mass fraction decreasing from 94 to 34%. The suspended solids content gradually increased from 6 to 66%, indicating a concentration effect typical of multi-component distillation systems.

Table 2. The results of the calculation for Solvent 1

Time [h]	Working temperature in the vessel [°C]	Working pressure in the vessel [bar]	Vapor flow from the vessel [kg/h]	Mass fraction of solvent [mass%]	Mass fraction of suspended material [mass%]	Amount of liquid flow in the vessel [kg/h]	Amount of steam in the vessel [kg]	Quantity of liquid in the receiving vessel [kg]	Amount of steam in the receiving vessel [kg]
0.00	20.00	1.01	0.00	0.94	0.06	0.00	0.31	0.00	0.00
1.25	49.04	0.50	51.93	0.94	0.06	124.61	0.13	2.09	0.00
2.51	54.68	0.50	55.05	0.90	0.10	113.96	0.14	73.79	0.00
3.76	59.08	0.50	52.28	0.86	0.14	112.32	0.15	140.89	0.00
5.02	62.02	0.50	50.38	0.83	0.17	110.92	0.15	205.10	0.00
6.27	63.78	0.50	49.21	0.79	0.21	109.76	0.15	267.44	0.00
7.53	64.78	0.50	48.51	0.76	0.24	108.77	0.15	328.66	0.00
8.78	65.37	0.50	48.08	0.72	0.28	107.90	0.15	389.20	0.00
10.04	65.73	0.50	47.48	0.69	0.31	107.12	0.15	449.29.	0.00
11.29	66.00	0.50	47.54	0.65	0.35	106.40	0.15	509.06	0.00
12.54	66.25	0.50	47.29	0.62	0.38	105.73.	0.15	568.53	0.00
13.80	66.510	0.50	47.01	0.58	0.42	105.11	0.15	627.67	0.00
15.05	66.82	0.50	46.68	0.55	0.45	104.53	0.15	686.42	0.00
16.31	67.16	0.50	46.27	0.51	0.49	104.00	0.15	744.71	0.00
17.56	67.65	0.50	45.76	0.47	0.53	103.51	0.15	802.41	0.00
18.82	68.20	0.50	45.14	0.44	0.56	103.07	0.15	859.41	0.00
20.07	68.88	0.50	44.37	0.41	0.59	102.67	0.15	915.53	0.00
21.32	69.71	0.50	43.45	0.37	0.63	102.33	0.15	970.58	0.00
22.58	70.70	0.50	42.33	0.34	0.66	102.03	0.15	1024.35	0.00

Solvent 2 was tested in a distiller, and the calculation results are shown in Table 3. Solvent 2 is a mixture with the following composition: 70-80% methyl acetate, 10-13% xylene, 7-10% methanol, 3-5% 2-butoxyethanol. The mixture with a narrower boiling range dominated by methyl acetate, showed higher initial vapor flow peaks due to its lower boiling point (40.5 °C at 0.5 bar). The limited amount of liquid transferred to the receiver can be attributed to azeotropic composition, increased solvent losses due to high volatility, or lower separation performance at lower operating temperatures. Nevertheless, the mass fraction of suspended material increased steadily from 10 % to 57 %, indicating successful separation and partial purification.

Table 3. The results of the calculation for Solvent 2

Time [h]	Working temperature in the vessel [°C]	Working pressure in the vessel [bar]	Vapor flow from the vessel [kg/h]	Mass fraction of solvent [mass%]	Mass fraction of suspended material [mass%]	Amount of liquid flow in the vessel [kg/h]	Amount of steam in the vessel [kg]	Quantity of liquid in the receiving vessel [kg]	Amount of steam in the receiving vessel [kg]
0.00	20.00	1.01	0.00	0.90	0.10	0.00	0.31	0.000	0.31
1.05	30.09	0.50	1.03	0.90	0.10	131.37	0.12	103.52	0.12
2.10	40.50	0.50	55.23	0.86	0.14	120.13	0.15	103.67	0.15
3.15	43.00	0.50	53.00	0.81	0.19	117.74	0.15	103.85	0.15
4.20	46.12	0.50	49.83	0.76	0.24	115.49	0.15	104.05	0.15
5.25	49.88	0.50	45.67	0.71	0.29	113.36	0.15	104.29	0.15
6.30	54.34	0.50	40.61	0.67	0.33	111.41	0.15	104.58	0.15
7.35	59.37	0.50	34.99	0.63	0.37	109.68	0.15	104.96	0.15
8.40	64.61	0.50	29.38	0.59	0.41	108.22	0.15	105.46	0.15
9.46	69.53	0.50	24.39	0.57	0.43	107.04	0.15	106.13	0.15
10.51	73.66	0.50	20.40	0.54	0.46	106.13	0.15	107.04	0.15
11.56	76.86	0.50	17.43	0.52	0.48	105.46	0.15	108.22	0.15
12.61	79.23	0.50	15.27	0.50	0.50	104.96	0.15	109.68	0.15
13.66	80.99	0.50	13.67	0.49	0.51	104.58	0.15	111.41	0.15
14.71	82.32	0.50	12.45	0.47	0.53	104.29	0.15	113.36	0.15
15.76	83.38	0.50	11.47	0.46	0.54	104.05	0.15	115.49	0.15
16.81	84.25	0.50	10.65	0.45	0.55	103.85	0.15	117.74	0.15
17.86	85.00	0.50	9.94	0.44	0.56	103.67	0.15	120.13	0.15
18.91	85.67	0.50	9.29	0.43	0.57	103.52	0.15	131.37	0.15

Solvent 3 was tested in a paint recycling device, and the calculation results are shown in Table 4. Solvent 3 is a mixture with the following composition: 70-80 % toluene, 20-30 % ethyl acetate, which requires a higher temperature of the heating oil to reach its boiling range (79.3 °C at 0.5 bar). The vapor flow rate reached about 47 kg/h after 2.5 h. This solvent mixture showed a more gradual and efficient increase in the receiving vessel content (up to 410 kg), indicating good distillation performance and significant solvent recovery potential. The mass fraction of suspended material increased from 10 to 51%, which is consistent with trends observed for other solvents.

Table 4. The results of the calculation for Solvent 3

Time [h]	Working temperature in the vessel [°C]	Working pressure in the vessel [bar]	Vapor flow from the vessel [kg/h]	Mass fraction of solvent [mass%]	Mass fraction of suspended material [mass %]	Amount of liquid flow in the vessel [kg/h]	Amount of steam in the vessel [kg]	Quantity of liquid in the receiving vessel [kg]	Amount of steam in the receiving vessel [kg]
0.00	20.00	1.01	0.00	0.90	0.10	0.00	0.31	0.00	0.00
0.67	22.97	0.67	0.39	0.90	0.10	126.21	0.12	0.00	0.22
1.33	36.39	0.50	0.06	0.90	0.10	124.90	0.09	0.00	0.29
2.00	65.10	0.50	0.51	0.90	0.10	124.71	0.13	0.09	0.36
2.67	80.69	0.50	47.40	0.89	0.11	110.11	0.19	14.68	0.40
3.34	82.90	0.50	46.09	0.86	0.14	109.02	0.19	45.36	0.40
4.00	84.30	0.50	44.75	0.83	0.17	107.92	0.19	75.61	0.40
4.67	85.16	0.50	43.89	0.80	0.20	107.02	0.19	105.11	0.40
5.34	85.71	0.50	43.32	0.77	0.23	106.22	0.19	134.15	0.40
6.00	86.10	0.50	42.92	0.75	0.25	105.50	0.19	162.89	0.40
6.67	86.40	0.50	42.59	0.72	0.28	104.84	0.19	191.39	0.40
7.34	86.66	0.50	42.27	0.69	0.31	104.22	0.19	219.68	0.40
8.00	86.93	0.50	41.95	0.66	0.34	103.64	0.19	247.75	0.40
8.67	87.20	0.50	41.60	0.63	0.37	103.09	0.19	275.60	0.40
9.34	87.51	0.50	41.21	0.60	0.40	102.57	0.19	303.21	0.40
10.01	87.85	0.50	40.77	0.58	0.42	102.09	0.19	330.53	0.40
10.67	88.23	0.50	40.27	0.55	0.45	101.63	0.19	357.54	0.40
11.34	86.67	0.50	39.70	0.52	0.48	101.22	0.19	384.19	0.40
12.01	89.17	0.50	39.06	0.49	0.51	100.83	0.19	410.43	0.40

Of the three mixtures studied, Solvent 1 provided the highest recovery of the liquid phase in the receiving vessel, indicating its favorable separation profile despite its complex composition. Its ability to achieve more than 1000 kg of recovered solvent within 22.5 hours emphasizes its recyclability and economic benefit in an industrial environment. The disadvantage lies in its relatively high content of residual suspended solids, which may require post-treatment. Solvent 2 does have a high initial vapor release, possibly due to the formation of an azeotrope or a lower volatilization threshold at the operating pressure. Nevertheless, the lower boiling point offers an energy-saving advantage that reduces heating time and costs. Solvent 3 exhibited the most balanced distillation dynamics, with a constant increase in recovered solvent and a controlled accumulation of suspended solids. Its moderate recovery rate, combined with a stable vapor flow and temperature control, could make it optimal for continuous recycling processes with minimal risk of fouling.

Operation at a reduced pressure of 0.5 bar proved to be effective in all three experiments, as it improved distillation by lowering the boiling points and minimized the risks of thermal degradation. The gradual increase of the solid phase fraction in the residual vessel indicates efficient phase separation, which is crucial for reducing the volume of hazardous waste. The relatively low mass fractions of suspended solids (51–66%) at the end of the process confirm that the majority of volatile organics were successfully removed, contributing to safer handling and reduced environmental impact. Overall, the data obtained demonstrate the suitability of low-pressure distillation for the treatment and reuse of solvent waste from paint recycling processes. Each type of solvent has unique advantages depending on its composition, boiling behavior, and energy requirements, which can be exploited for specific industrial applications.

CONCLUSION

The worldwide problem of pollution of soil, water, and air is considerably aggravated by the improper disposal of paints that are no longer used for various reasons. To protect the environment and to to achieve economic savings on the disposal and incineration of hazardous waste resulting from the use of products from the paint industry, a device for recycling paints and other organic solvents has been developed. The technology for recycling waste mixtures presented in this paper is based on a distillation process. The advantage of this device compared to conventional devices of this type is that it contains a distillation column that enables more efficient distillation of a specific solvent from a mixture of recyclable solvents. In addition to the device, a mathematical model based on technical and technological as well as thermodynamic principles was developed which provides useful information on the distillation process, the recycled mixture, and the quality and quantity of the products obtained, which meet the requirements and needs of users. Further research should focus on the design of larger paint recycling plants, with emphasis on techno-economic analysis, planning, and application.

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Nomenclature

M – mass of mixture in a distiller (kg)
M_s – mass of dry matter in the distiller (kg)
M_r – mass of solvent *r* in the distiller (kg)
h – specific enthalpy of the mixture in the distiller (kJ/kg)
h_i – specific enthalpy of the inlet mixture (kJ/kg)
h_o – specific enthalpy of the outlet mixture (kJ/kg)
Q – heat transferred to the system (kW)
T – temperature in the distiller (°C)
P – pressure in distiller (bar)
x – mass fraction of components in mixture
t – time (h)
U – heat transfer coefficient of heating fluid and mixture in distiller unit ($kJ \cdot m^{-2} \cdot s^{-1} \cdot °C^{-1}$)
A – heat transfer area (m^2)
$\overline{T}_{oil}$ – average temperature of oil (°C)

$\dot{m}_{oil}$ –mass flow of oil (kg/s)

$c_{P,oil}$ – heat capacity of oil (kJ/kg/°C)

$T_{oil,inlet}, T_{oil,outlet}$ – inlet and outlet temperature of oil from the thermal jacket

$\dot{m}_i$ – inlet mass flow of feed in distiller unit (kg/s)

$\dot{m}_o$ – outlet mass flow of feed in the distiller unit (kg/s)

x_u^r – mass fraction of solvent *r* in feed

x_u^s – mass fraction of dry matter in feed

y_u^r – mass fraction of solvent *r* in gas phase

ρ – density of mixture in distiller unit (kg/m^3)

V – volume of distiller unit (m^3)

E – energy of mixture in distiller unit (kJ)

K_r – equilibrium constant gas-liquid for the solvent *r*

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Izvod

RECIKLAŽA I PONOVNA UPOTREBA ORGANSKIH RASTVARAČA IZ OTPADNH BOJA

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Otpadne boje i drugi premazi koji su ostali neiskorišćeni ili kojima je istekao rok trajanja, mogu se reciklirati pre odlaganja. Ovo je važno jer se tako smanjuje zapremina otpada koji se odlaže na deponiju, a i omogućava se ponovna upotreba određene količine recikliranih komponenti. Na ovaj način se doprinosi ne samo smanjenju otpada, već i poboljšanju ekološke održivosti, uz ostvarenje značajnih ekonomskih ušteda.
U ovom radu je predstavljen uređaj za reciklažu boja koji radi na principu destilacije. Za razliku od klasičnih destilatora, koji rade na principu destilacije sa kondenzatorom, predloženi sistem se sastoji od glavnog suda sa destilacionom kolonom. Prednost ovog uređaja je što se frakcije sa sličnim temperaturama isparavanja mogu lakše razdvojiti.
Razvijen je matematički model zasnovan na termodinamičkim principima i procesnim parametrima, kako bi se predvidelo ponašanje procesa destilacije za različite rastvarače. Na osnovu stvarnih parametara procesa, kao što su radni pritisak, sastav i brzina protoka napojne smeše, temperatura isparavanja itd., proračunavaju se vreme, sastav, kvalitet i količina za svaku od dobijenih komponenti, što predstavlja ekonomsku opravdanost ovog procesa. Tri rastvarača sa različitim sastavima su testirana korišćenjem podesivih parametara procesa destilacije, a rezultati daju uvid u tok procesa destilacije, karakteristike reciklirane smeše, i kvalitet i prinos recikliranih proizvoda.

Ključne reči: boje, reciklaža, destilacija, matematičko modelovanje, optimizacija