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Management and Control of Industrial Effluents Discharged to Public Sewers: A Case Study

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***Abstract*—**An overview of the important aspects of managing and controlling industrial effluent discharges to public sewers namely sampling, characterization, quantification and legislative controls has been presented. The findings have been validated by means of a case study covering three industrial sectors namely, tanning, textile finishing and food processing industries. Industrial effluents discharges were found to be best monitored by systematic and automatic sampling and quantified using water meter readings corrected for evaporative and consumptive losses. Based on the treatment processes employed in the public owned treatment works and the chemical oxygen demand and biochemical oxygen demand levels obtained, the effluent from all the three industrial sectors studied were found to lie in the toxic zone. Thus, physico-chemical treatment of these effluents is required to bring them into the biodegradable zone. K_L values (quoted to base e) were greater than 0.50 day^{-1} compared to 0.39 day^{-1} for typical municipality wastewater.

***Keywords*—**biodegradability, industrial effluent, pollution control, public sewers

I. INTRODUCTION

POLLUTION of water by process industries located within urban settlements is a cause of concern in most parts of the world [1]-[4]. Process industries are normally located near or within urban centres due to proximity to human labour, consumers and access to a well-developed infrastructure. Most process industries located within urban areas discharge their liquid effluent into public owned treatment works (POTW) for subsequent treatment and disposal into natural water courses. However, most POTW were designed to treat domestic waste and in most cases cannot adequately handle complex industrial waste, resulting in the pollution of downstream natural water courses. The pollution of natural watercourses due to the discharge of poor quality effluents poses a serious threat to human beings and aquatic organisms since they rely on this water for sustenance.

This problem is exacerbated in developing countries where rapid urban population growth and increased industrialization has increased the hydraulic load and complexity of effluent handled by POTW [5]-[7]. In most instances this is accompanied by severe corrosion and failure of most sewer lines conveying industrial effluents leading to pollution of underground water resources. Due to limited fresh water resources in most parts of the world there is a need to develop a practical and scientific guide to the management and control of industrial effluent discharges to municipality sewers, if pollution of downstream water resources is to be addressed.

Various approaches have been implemented to properly manage industrial effluent discharges ranging from pollution prevention, end-of-pipe treatment methods and legislative control based on effluent discharge standards. The later has been largely used by municipalities and other administrative bodies as a tool for pollution control.

However, its success has been largely limited by the lack of properly designed sampling programmes and lack of adequate resources to effectively monitor industrial effluent discharges [4], [7]. Legislative control alone, cannot address this problem thus an integrated approach encompassing pollution prevention and control is required. This normally requires a more detailed understanding of the processes generating the effluent, complete characterization and quantification of the effluent streams, and an understanding of the economic limitations faced by industry in addressing pollution control and prevention. Given the limited resources and skills in most municipalities in developing countries, there is a need to develop a practical but scientific guide to enable effective management of pollution control activities.

This paper seeks to present an integrated approach to the management of industrial liquid effluents discharged to POTW. The paper addresses issues from design of sampling programmes, characterization and quantification of effluents, municipality regulatory standards and best practicable technology for effluent treatment required to meet local sewer requirements. A case study is presented based on a survey of three sectors of industries namely tanneries, food processing (i.e edible oil and sugar refinery industries) and textile finishing industries. The general quality of effluent discharged from each sector of industry is well documented in literature [8], however, only those aspects that have a significant effect on the amenability of the effluent to treatment in POTW and impact the sewer conveyance system will be addressed. General guidelines on effluent characterization and quantification are presented, regulatory standards and their impact on process industries and minimum pre-treatment requirements are presented. These are based on case studies in the three sectors of industries selected.

II. EXPERIMENTAL

A. Methodology

Three sectors of industries were used as case studies, namely the tannery, textile finishing and food processing industries (namely, edible oil and sugar refining industrial sectors). The major pollution indicator parameters considered were the pH, total suspended solids (TSS), chemical oxygen demand (COD), 5-day carbonaceous biochemical oxygen demand ($CBOD_5$) and total dissolved salts (TDS). These pollution indicator parameters were considered to give a good indication of the effect of the effluent on the sewer conveyance system and its amenability to treatment in POTW. The volume of effluent was also measured in order to quantify the effluent inorganic and organic load.

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The effluent TDS and COD were used in the calculation of the inorganic and organic load respectively, since these parameters represent the cumulative contribution of different inorganic and organic compounds.

B. Apparatus and Experimental Methods

Evaluation of the best sampling strategy was done based on the variation of the effluent load. The volume of effluent discharged was quantified using a Millitronics open channel monitor (OCM III, Model PL-505) in conjunction with a remote ultrasonic transducer (Model ST-25) with an in built temperature sensor. The pH and TDS were measured on the spot and the COD, $CBOD_5$ and TSS were measured in the laboratory within 24 h after sample collection. The samples were analysed using standard methods as outlined in the Standard Methods Handbook (AWWA, APHA and WEF 1998). Effluent pH and TDS were measured using a Hach pH meter (Model 51935-00) and Hach conductivity meter (Model 51975-03) with a temperature sensor respectively. COD was determined by closed reflux method using a Hach COD reactor (Model 45600) followed by calorimetric determination of Cr^{3+} at a wavelength of 620 nm using a Hach spectrophotometer (Model DR 2010). The respirometric method was used to determine the $CBOD_5$ using a manometric respirometer (Hach BOD trak, Model 26197-01). TSS were determined by measuring the amount of light scattered by the solids at a wavelength of 810 nm, using a Hach spectrophotometer (Model DR 2010).

III. RESULTS AND DISCUSSION

A. Sampling strategies

Three sampling strategies of paramount importance in effluent monitoring, namely random sampling, random sampling with time weighting and systematic sampling were evaluated [9]. Random sampling is a method of sampling where the chances of obtaining different concentration values of a determinant are precisely those defined by the probability distribution of the determinant in question. Systematic sampling involves the collection of samples at predetermined intervals, often equally spaced in time. Random sampling with time weighting involves weighing each measured concentration by the time interval represented by that observation. A comparison of the three sampling strategies using the variability of the effluent load showed that systematic sampling was the best sampling strategy for industrial effluents [7]. It was demonstrated that the number of samples and cost of sample analysis can be greatly reduced by using systematic sampling instead of random sampling while not compromising the quality of the data obtained. Peak pollutant levels were also effectively detected using systematic sampling and sampling after every 8 days was found to be satisfactory and the statistical benefits of systematic sampling were realized. However, the successful implementation of systematic sampling requires the availability of adequate resources which in most instances are not available in most developing countries. In order to address this resource constraint it was recommended that implementation of systematic sampling be combined with the "polluter pays principle" [7]. This ensures that the generator of the waste adequately pays for its conveyance, monitoring and treatment.

The trade tariff formula (TFF) used to apply the "polluter pays principle" to industrial dischargers should be carefully designed to ensure it addresses the problem of pollution without being a financial burden to industry. A guideline based on the fixed-variable method of expenditure allocation and depreciation has been developed and used by many South African Municipalities [10]. A modified version of this formula was used to calculate the tariff charge for each sector of industries considered in the case study using both historical random sampling data and data obtained by systematic sampling [7]. From the results obtained the benefits of systematic sampling were demonstrated and the approximate cost to be borne by each industrial sector calculated.

B. Overview of legislation governing the discharge of industrial effluents

Dischargers to POTW are required to comply with local sewer regulations. The regulations normally consist of bylaws that specify the maximum acceptable water quality standard for discharge into sewer and other regulations pertaining to the management of effluent discharges. The quality of the effluent is evaluated based on the concentration of various physical and chemical parameters outlined in the bylaws. An overview of the different sewer discharge standards used by different municipalities is shown in Table I for the parameters relevant to the sectors of industries studied.

TABLE I
SEWER EFFLUENT STANDARDS IN VARIOUS MUNICIPALITIES

Parameter (mgl^{-1} unless specified)	Johannesburg	Pretoria	Bulawayo	Hong Kong	Singapore
pH (pH units)	6	6-10	6.5- 12	6- 10	6- 9
COD	n.s.	5000	2000	2000	600
BOD	n.s.	n.s.	n.s.	800 (5d)	400 (5d)
Total Dissolved Salts (TDS)	n.s.	2000	n.s.	n.s.	3000
Suspended Solids	2000	600	600	800	400
Sulphides	50	25	n.s.	1	1
Sulphates	1800	300	300	600	1000
Total Metals	50	20	20	1 (toxic)	10
Soap, oils and grease (SOG)	n.s.	n.s.	10	n.s.	n.s.

Note: Adopted from bylaws
n.s. = not specified

The value specified for each pollution indicator parameter varies with each municipality and is normally based on the design capacity of each POTW. Most municipalities do not measure BOD on a routine basis largely because of the time it takes to complete the analysis and economic constraints, thus it is not specified in most instances. Other municipalities use the permanganate value (PV) or the 4 hr oxygen absorbed (OA) as a measure of the organic content of the effluent in place of the COD. The maximum discharge volume is not specified as a standard in most municipalities; however, an estimate of the volume is normally used for tariff calculations.

For effective pollution control the sewer effluent standards should be based on the receiving water quality since POTW discharge their effluent directly to natural water courses. In cases where the quality of the water is already under stress, even effluent complying with the current standards can still have negative effects.

However, due to lack of adequate hydrological data most developing countries adapt uniform standards for direct dischargers (discharging directly to natural water courses) instead of receiving water quality standards. This encourages the location of industries at worst sites, from an environmental point of view and can be over restrictive causing economic dislocations for some industrial sectors.

There is also a need to adopt standards tailor made for each category of industries for some specific pollution indicator parameters, as some of the limits are too stringent for some sectors of the process industry. For example adopting a standard of 50 mgl^{-1} or less for SOG is not easy to achieve for edible oil industries and ostrich tanneries without biological treatment. Pre-treatment of effluent from these industries to meet this standard offsets the economic incentives of discharging to POTW. There is also a need to distinguish between oils of vegetable origin and mineral origin in the sewer standards. Some municipalities adopt more stringent SOG limits as a result of not distinguishing between oils of vegetable origin and mineral origin. A standard guideline of 100 mgl^{-1} SOG is recommended by many sanitary engineers [11]. Even this standard has been considered to be too stringent, considering that the biodegradability of edible oils is almost twice that of typical municipality wastes and higher than that of petroleum oils [12]. Since vegetable oils are more biodegradable than mineral oils a relaxed standard should be adopted for them for specific sectors of industries.

A limit of 600 mgl^{-1} or less for sulphates is also not technically feasible for tanneries. Research by the Cement and Concrete Association has revealed that significant damage of ordinary Portland cement sewers is unlikely to occur if the sulphate concentration in the sewage flow is less than 1400 mgl^{-1} [13]. Since there is some degree of dilution in trade effluent sewers, a general standard sulphate limitation of 1000 mgl^{-1} has been recommended to provide an additional safety margin [13]. Thus more stringent limits are only justified if the receiving water quality is already under severe stress.

Implementation of the “polluter pays principle” requires a shift from the use of concentration based standards to the use of pollutant loads as a means of pollution control. Pollutant load based standards deter industries from using effluent dilution as a means of meeting concentration based discharge limits and encourages industries to minimize the amount of effluent discharged or fresh water utilization. Implementation of this principle will also ensure that industries have a financial incentive in moving away from pollution control to pollution prevention. The scope of industrial pollution legislation has been widening from a single media approach, through integrated pollution control (IPC), to integrated pollution prevention control (IPPC) and further towards sustainable development [14]. This is reflected in the development of the environmental legislation in Europe and the United States of America. However, in most developing countries the current legislation consists only of emission standards, which tend to encourage industries to focus more on pollution abatement other than pollution prevention.

In order to curb pollution problems in most developing countries legislation addressing reduction of pollutants at source should be implemented.

C. Sampling and sample analysis.

Information on industrial effluent sampling and analysis is well documented in literature [15], [16]. Two sample collection modes are normally employed manual sampling and automatic sampling. Manual sampling is predominantly used in developing countries because of its simplicity and cost; however, it has many drawbacks especially if it is to be used for regulatory purposes. For pollution control activities, most municipalities employ trade effluent inspectors to collect effluent samples, and they normally work on a day shift. Thus, it is difficult to collect samples during odd hours and to perform event sampling over an extended period of time. If the benefits of systematic sampling are to be realized, there has to be a shift to automatic sampling. The financial implications can be offset by effective application of the “polluter pays principle” combined with systematic sampling. In recent years manual sampling has lost ground to automatic sampling at a rapid rate [17]. Since the comprehensive reviews of automatic samplers [18], [19] there has been a general increase in the type and number of commercial instruments. Stringent legislation and regulations have created a need for advanced sampling programmes. In most industrialized countries sampling is now mostly conducted with automatic samplers.

The Standard Methods Handbook [15] gives a comprehensive description of all the analytical methods and instrumentation used in water and wastewater analysis taking into account recent developments in the field of analytical chemistry. For purposes of monitoring industrial effluent discharged to sewer, parameters that express the cumulative organic, inorganic and physical characteristics of the effluent such as COD, TDS, pH and TSS, respectively, are helpful in assessing the effect of the effluent on the sewer conveyance system and its amenability to treatment in POTW. Selective analysis of individual chemical constituents should only be conducted for effluent from specific industrial sectors in cases where these constituents have been identified to have a significant effect on the sewer system e.g. sulphides and sulphates in tanneries. Measurement of the COD as an estimate of the organic content is more preferable than the use of the PV or OA value since virtually all the organic compounds in the sample are oxidised using dichromate oxidation as opposed to permanganate oxidation.

D. Effluent quantification

Industrial effluent quantification is performed using direct flow measurement or approximate measurement methods. Direct flow measurements involve the use of a primary element (flumes or weirs) in conjunction with a secondary element (staff gauge, ultrasonic meter, bubbler, dipping probe, float, pressure sensor and capacitance probe). However, there are other meters that can compute flow without a primary element by measuring both the velocity and head of the wastewater e.g. ultrasonic meters with velocity sensor or robotically operated magnetic flowmeter probe. Approximate flow measurement methods include the use of water meters on influent lines and container (or equalisation tank) and stopwatch technique.

The most commonly used method for flow monitoring in industry is the use of a primary element in conjunction with a flow meter [20]. Most primary elements need adequate maintenance to give reliable results, a factor that has been shown to be neglected by many industries [21]. As a result, water-balancing exercises have shown that most meters yield questionable volumetric data. Thus for regulatory purposes by municipalities water meter readings corrected for evaporative and consumptive losses are recommended for municipalities as the best way of approximating the volume of effluent discharged to sewer.

E. Case study results

The raw (before pre-treatment) effluent quality characteristics for the major pollution indicator parameters deemed most important from the view point of determining the impact of the effluent on the sewer conveyance system and amenability to treatment in POTW are shown in Table 2.

TABLE II
EFFLUENT CHARACTERISATION RESULTS

Parameters (mgl^{-1} unless stated)	Range of values for each industrial sector			
	Tannery	Textile finishing	Sugar Refining	Edible oil processing
pH (pH units)±0.20	4.8-11.3	5.2-11.8	4.3-7.4	2.3-12
COD±26	2100-41400	3700-10,200	6500-54800	2500-65,800
$CBOD_5$±10	1265-13871	770-5000	4138-14565	1750-19,700
TSS±10	304-7420	40-3840		800-16,000
TDS±5	1120-22900	170-20,100	242-1257	570-9000
Sulphate	90-2000	20-180	15-330	45-12,800
Sulphide	0.4-346			
$CBOD_5$:COD	0.1-0.7	0.2-0.5	0.2-0.6	0.2-0.7
Volume (m^3/day)	13-21	21-764	9.6-72.3	26.4-79.2
Inorganic load (kg TDS/day)	13-462	5- 15,356	1-91	96-554
Organic load (kg COD/day)	24-836	100-7793	21-3692	23-1073

There was a wide variation in the range of values obtained for each pollution indicator parameter reflecting the variation in effluent quality obtained from different processing stages employed in product processing. This is a characteristic feature of effluent discharges in most processing industries. Thus, effluent equalisation can help prevent shock loads to both the pre-treatment plants and POTW and help to produce a low strength consistent effluent quality that is more amenable to treatment. The effluent discharged from most of the industries considered was largely composed of organic material with the exception of the textile industrial sector. The $CBOD_5$:COD has been used as an indicator of the ability of a substance to be broken down into simpler substances by bacteria. Samudro and Mangkoedihardjo [22] formulated a method for zoning BOD:COD ratios based on the way the organic containing material will be treated or disposed. The BOD:COD ratios were classified into three zones namely toxic zone, biodegradable zone and acceptable/stable zone.

The sector of industries considered in the case study discharge their effluents to POTW employing physical treatment (screening and clarification) followed by biological treatment (aerobic digestion). Based on the treatment processes employed in the POTW and the COD and BOD levels obtained, the effluent from all the three industrial sectors studied can be classified as in the toxic zone (Table 2). The ratio of the $CBOD_5$:COD obtained from the results was approximately in the range of 0.2-0.7. Thus, physico-chemical treatment of these effluents is required before discharge to sewer to bring the effluent into the biodegradable zone (output BOD < 100 mg/L, COD < 500 mg/L and BOD/COD ratio > 0.1). This ensures that the effluent is amenable to biological treatment which is employed as a final polishing step in the POTW before effluent discharge. To reduce the financial burden borne by industries in treating their effluent, it is necessary only to treat the effluent to an acceptable level for discharge into sewers taking into account the treatment processes employed in POTW. Generally sedimentation (combined with the use of coagulants and flocculants) followed by adsorption onto activated carbon or other low cost adsorbents has been found to be an effective pre-treatment option for removing inorganic and non-biodegradable organic material [23], [24], [25], [26], [27]. Equalisation of screened effluent and sedimentation aids in reducing the organic load and colour of the effluent to ensure that the adsorbent does not need frequent regeneration. Filtration of the clarified effluent using a granular filter before the adsorption step can also be helpful in reducing the level of suspended solids, thus further reducing the frequency of adsorbent regeneration.

The carbonaceous biochemical oxygen demand (CBOD) reaction-rate constant values (K_L-quoted to base e) for composite samples collected from each of the industrial sectors was calculated using the Thomas Slope method (1), [28].

$$\left(\frac{t}{y}\right)^{1/3} = \left(2.3K_L L\right)^{-1/3} + \frac{K_L{}^{2/3}}{3.43L^{1/3}}.t \tag{1}$$

Typical Thomas slope plots for each of the sectors of industries studied were derived from the respective BOD plots and are shown in Fig. 1. The K_L value of a particular waste usually displays little variation once determined [28], thus these values are representative of the K_L value for the equalized raw effluent from each industrial sector studied. The K_L values (quoted to the base e) were calculated from the slope and intercept of the Thomas slope plots (Fig. 1) using (2) and are shown in Table III.

$$K_L = 6.01 \times \left(\frac{\text{slope}}{\text{intercept}}\right) \tag{2}$$

TABLE III
K_L VALUES FOR COMPOSITE EFFLUENT SAMPLES FROM THE INDUSTRIES STUDIED

Parameter	Industrial Sector			
	Tannery	Textile finishing	Sugar Refining	Edible oil processing
K_L (day^{-1})	0.51	0.55	0.71	0.64

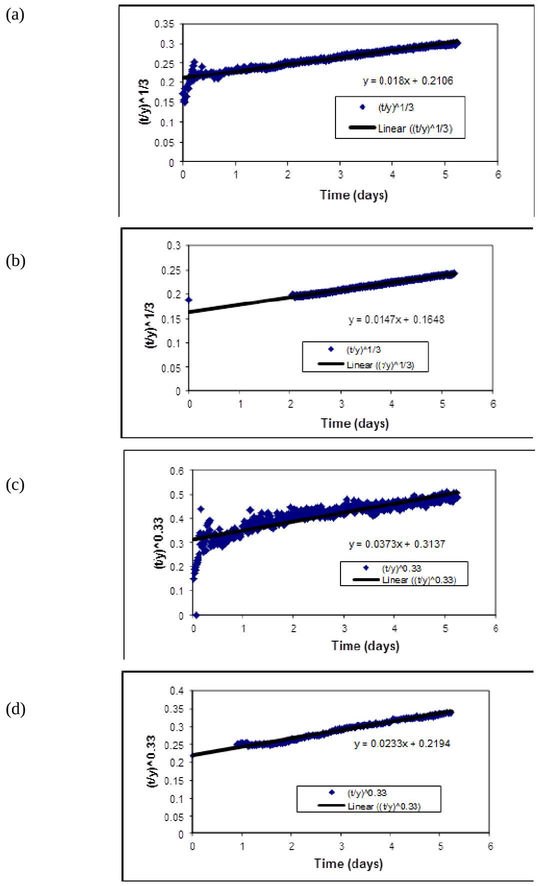

Fig. 1 Thomas slope plots: (a) Tannery; (b) Textile; (c) Sugar Refining; (d) Edible oil Refining

An acceptable K_L value (quoted to base e) for discharge into municipality sewers is approximately 0.39 day^{-1} or greater, thus the effluent from these process industries is suitable for discharge into municipality sewers in terms of biodegradability. Furthermore, the K_L values obtained were all higher than that of typical municipality wastewater (i.e. 0.39 day^{-1}) [12]. Thus, with proper pre-treatment to remove the non-biodegradable fraction these effluents can be effectively treated in POTW.

Analysis of the BOD curve using the Thomas slope method can help in identifying how easily the microorganisms employed for biodegradation acclimatize to the effluent and whether there are toxic materials interfering with the process of biodegradation. Analysis of the BOD curves for the industries considered, revealed that there is an initial lag before rapid biodegradation commences ranging from a few hours to almost 1-2 days as in the edible oil refining and textile finishing effluents. An analysis of the BOD curve for the textile effluent using the Thomas slope method gave a negative slope for the first time segment (day1-2) of the curve indicating the presence of toxic material interfering with biodegradation. While, the BOD respirometric method can not identify specific toxic components in the effluent it can serve as a guide in terms of identifying pre-treatment standards before discharge of effluent to sewer and pollution prevention interventions aimed at eliminating possible toxic materials used during processing.

In terms of potential impact on the sewer conveyance system, only the effluent from the tannery and edible oil processing is likely to cause severe corrosion of sewers due to the high organic load coupled with sulphate concentrations above 1400 mgl^{-1}. The presence of high concentrations of oxygen demanding waste results in the depletion of dissolved oxygen in the effluent, giving rise to anaerobic conditions. When this is coupled with high sulphate concentrations in the effluent it leads to the reduction of sulphates to sulphides resulting in the corrosion of sewer lines. Thus, as a safety precaution it is advisable that industries discharging effluent with a high organic load and sulphate concentration in excess of 1400 mgl^{-1} should not be located more than 7 km from the POTW without adequate pre-treatment facilities. Longer sewer residence time has been found to create ideal conditions for anaerobic bacterial reduction of inorganic sulphates to sulphides. The soap, oils and grease (SOG) normally associated with such effluents can also result in the clogging of sewer pipes and pumps.

While pollution prevention forms an integral part of pollution control, opportunities for pollution prevention available for each sector of industry have not been presented since there were considered to be outside the scope of this paper.

IV. CONCLUSION

Systematic sampling after an interval of 8 days was found to be the best sampling strategy for pollution control. When coupled with the “polluter pays principle” the resources required to successfully implement this sampling strategy can be generated. However, successfully implementation of the “polluter pays principle” requires a shift from the use of concentration based standards to the use of pollutant loads and automatic sampling as a means of pollution control. To avoid pollution of natural watercourses by POTW, sewer effluent discharge standards should be based on the receiving water quality in that area. Uniform standards can be over restrictive causing economic dislocations for some industrial sectors and tend to encourage location of industries at unsuitable sites from an environmental point of view. Parameters expressing the cumulative organic, inorganic and physical characteristics of the effluent such as COD, TDS, pH and TSS, respectively, are more useful in assessing the effect of the effluent on the sewer conveyance system and its amenability to treatment in POTW.

Analysis of the individual chemical constituents is necessary for constituents that have been identified to have a significant effect on the sewer system. For regulatory purposes effluent volume should be estimated based on water meter readings corrected for evaporative and consumptive losses. Characterization of raw effluent from selected process industries revealed a wide variation in the effluent quality and quantity over time, characteristic of the different processing stages employed in product processing. Based on the treatment processes employed in the POTW and the COD and BOD_5 levels obtained, the effluent from all the three industrial sectors studied were found to lie in the toxic zone. Thus, physico-chemical treatment of these effluents is required to bring them into the biodegradable zone and ensure local sewer standards are meet. The K_L values obtained were greater than 0.50 day^{-1} which is far higher than that for typical municipality wastewater (i.e. 0.39 day^{-1}).

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