RECYCLING OF MEDIUM DENSITY FIBREBOARDS – A REVIEW

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ABSTRACT

Production of Medium Density Fibreboards (MDF) is one of the growing woodworking industries. It has been found that a quarter of the produced MDFs have a life cycle of up to five years, and by ten years, this amount has increased to fifty percent. There is no established industrial practice for recycling that type of waste. That, together with the fact that some countries have banned the dumping of these panels in landfills, poses significant challenges.

There are currently two main research directions on MDF recycling, namely with and without pre-treatment. In both cases, with an increase in the content of recycled fibres, a deterioration in the properties of the panels is observed. Still, the share of cut fibres and formaldehyde emissions from the boards are reduced during the preliminary treatment, mainly by hydrolysis.

In the present manuscript, a review and analysis of MDF recycling methods are performed. On that base, conclusions and recommendations are derived.

Key words: waste Medium Density Fibreboards, natural fibres, recycling, refining hydrolysis, electrolysis.

INTRODUCTION

The production of fibreboard panels is one of the sustainable wood processing industries. The total increase in the production quantities of this type of material for the period 2015 ÷ 2020 is approximately 10% (FAO). In 2020, worldwide, the production of fibreboards amounted to 118,111 million m^3. According to this indicator, the production of fibreboard panels ranks second, after plywood with a total amount of 118,395 million m^3 and before the production of particleboards – 101,987 million m^3.

The main share of the production of fibreboards in 2020 is the production by dry-process. This type of MDF and Hight Density Fiberboards (HDF) make up 74% of the total output. MDF is produced with 6 to 10% content of binders based on dry fibres. Urea-formaldehyde (UF) resin or modified melamine-urea-formaldehyde (MUF) resin is mainly used as a binder in that production (Mantanis, G. I. et al. 2017; Kutnar and Burnard 2014; Athanassiadou et al. 2015; Sandberg 2016). That leads to two main shortcomings of MDF: increased formaldehyde emissions and difficulties in recycling or disposal of the panels (Hui, W. et al. 2014; Ihná, V. et al. 2017; Khazipour, A. and Kües U. 2007).

It should be emphasized that the life cycle of the produced fibreboard panels is from 4 to 50 years (Irle, M. et al., 2019). Disturbing are the data presented in the cited study that 25% of MDF completes its life cycle up to 1 year, up to 5 years the share increases to 50%, up to 10 years its life cycle ends 80% of the panels, and up to 45 years 99%. A comparative analysis of the quantities of produced MDF and their life cycle can easily conclude the significant raw material potential that these waste quantities would represent, even with single recycling. The newly MDF will eventually be turned into waste, and the rate of that is likely to be rapid in the first few years and then gradually decline over time.

The conversion curve used to predict how much of the waste MDF is generated each year is shown in Figure. 1.

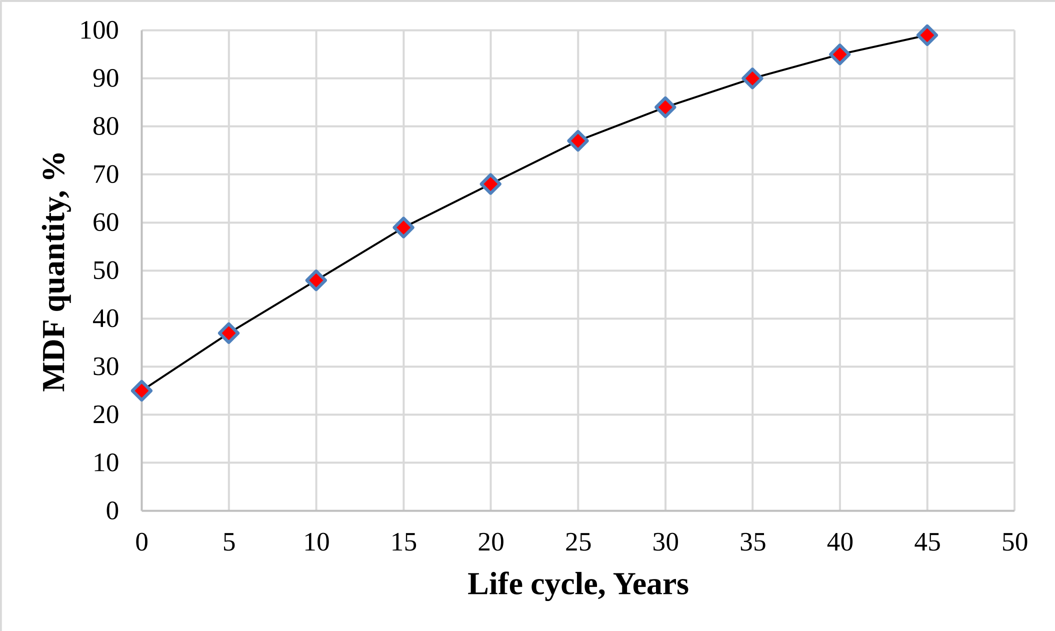

Figure 1: MDF life cycle as a percentage of the produced quantity, (Irle, M. et al. 2019)

It is estimated that in the first year, about a quarter of the production is turned into waste in the form of clippings, processing errors, losses during transportation and storage, etc. That assumption is in line with a study by (Mitchell and Stevens 2009), which found that only processing waste accounted for about 18% of MDF. After 45 years, it is assumed that almost all production has become waste. One can argue for the most appropriate form of the curve between 25% conversion to waste in the first year and 99% after 45 years. In this study, a 4-parameter symmetric sigmoidal model was used to generate a curve so that the average lifespan of all MDF products was 14 years. Therefore, introducing sustainable production practices to recycle MDF would lead to the preservation of valuable wood raw materials (Lykidis, C and Grigoriou, A. 2008; Kim, M.H. and Song H.B. 2014, Antov, P. and Savov, V. 2019). Due to synthetic binders, MDF is prohibited from incineration in the EU, and individual efforts are made to prevent this type of waste from being disposed of in general landfills. Such a ban already exists in Germany.

It should be noted that the recycling of particleboards is a widely introduced industrial practice (Michadicl, A. and Boeheme, C. 1995; Michaickly, A. 1997; Iždinský, J. et al., 2020;), the recycling of MDF has not yet been introduced in industrial conditions (Bütün Buschalsky, F.Y. and Mai, C., 2020; Hagel, S. and Saake, B. 2020). The main reason for this is that crucial issues need to be clarified, such as 1) the proportion of recycled wood fibres involved; 2) whether preliminary preparation and treatment are necessary; 3) whether the parameters of MDF production should be changed, with the participation of recycled fibres in their composition and others. In addition, there are explosive recycling methods, but due to their difficult applicability in modern MDF production, they are not very promising.

The directions for MDF recycling can be summarized in two groups: 1) recycling with the extraction of binders; 2) recycling without extraction of binders (Ahmadi, M. and Moezzipour, B., 2019). There are also two varieties in the second option: obtaining recycled fibres with a change in the regime factors during defibering; and obtaining recycled fibres without changing the regression factors (Nuryawan, A. et al., 2020). Whether other technological and regime factors should be modified in MDF production with the participation of recycled fibres in their composition also remains debatable (Irle, M. et al., 2019).

This work aims to review and analyze the methods used so far to recycle waste MDF.

RECYCLING OF WASTE MDF WITHOUT PRE-TREATMENT

A study fabricated fibreboard panels with 5% recycled fibres (Sala et al. 2020). In this study, the recycling was carried out in the refiner with steam evaporation at different pressures - 0.65; 0.90; 1.00; 1.06 MPa and, respectively, temperatures - 160; 170; 179 and 182°C. The hydrothermal treatment time was 3.2 min. In that study, there are no conditions for hydrolysis of UF resin, and therefore, the manufactured panels are without resin extraction. It was found that the bulk density of the pulp of recycled fibres increases with the increase of that indicator. The overall growth is 7%. Unfortunately, the lower bulk density at lower temperatures was due to the cutting of the fibres and not to the presence of cellulose fibrils. At higher refining temperatures, a better-quality fiberboard is fabricated from recycled fibres. It is optimistic that the panels manufactured with 5% recycled fibres meet the requirements of the standards.

Regarding formaldehyde emissions, it was found that there is a decrease in this indicator with increasing refining temperature. Panels with 5% recycled fibres and a refining temperature of at least 170°C meet the formaldehyde emission requirements of CARB 2 - below 4 mg/100 g, determined by the perforator method. The partial degradation of UF resin explains lower formaldehyde emissions in recycled fibres at higher refining temperatures.

A study by Mantanis et al. (Mantanis. G. I. et al. 2004) proposed a new approach to recycling MDF. This study aims to utilize "higher" levels of waste panels. An advantage of the study is that the experiments were conducted in industrial conditions. One hundred percent of wood raw material panels and panels with 75% wood raw material and 25% recycled MDF were produced. Additive 'A' in 0, 5 and 10% and additive 'B' in 0 and 1% are used for recycled MDF. Unfortunately, the type of these supplements is a trade secret. It is only stated that additive "A" is used for cross-linking in the adhesion system, and additive "B" is used to improve the properties of the panels. Most likely, the additive "B" is a formaldehyde scavenger. The 25% recycled fibre panels have higher formaldehyde emissions than the panels from natural fibres. Again, after adding the mentioned additives, the emissions of formaldehyde on the panels with the participation of recycled and with the participation of natural fibres are equalized.

Of interest is another study that has focused on the appearance of MDF and their machinability (Ormondroyd, G. A. et al.

2017). This study crushed waste MDFs into 20 x 10 mm cubes, immersed them in water for 72 hours and performed standard refining. Panels with natural fibres and those with up to 20% share of recycled fibres were fabricated. It was found that the participation of up to 20% of recycled fibres does not impair the appearance and machinability of the panels.

HYDROTHERMAL RECYCLING OF WASTE MDF

It has been found that liquid and a solid fraction are generated by waste MDF evaporation. The liquid fraction contains dissolved carbohydrates and lignin and a large amount of nitrogen and acids (acetic and formic). The acid factor, pH, of the liquid extract is about 8, significantly higher than that of the refining of natural lignocellulosic raw materials. That is mainly due to the high amount of ammonium hydroxide after the decomposition of the resins. The reuse of separated fibres in the production of new MDF is the most obvious possible recycling for this material. However, due to a combination of effects such as fibre shortening, changes in the chemical composition of the fibres and resin residues found on their surface, there is a significant deterioration in the mechanical properties of the panels fabricated from recycled fibres and those from natural ones (Hagel S, and Saake, B. 2020; Hagel, S et al. 2021).

The primary type of adhesive in MDF production is UF resin. Along with many advantages, this resin has two serious disadvantages - high emissions of formaldehyde and practically no resistance to hydrolysis (Roffael E. 2002; Roffeal and Kraft, R. 2004). The second disadvantage of UF resin, namely that it is not resistant to hydrolysis, becomes an advantage in recycling MDF. The methods for extracting and separating UF resin from panels are mainly based on hydrolysis (Lubis, M.A.R. et al. 2021). Analyzes of the coverage of the fibres with UF resin in the composition of MDF have shown that there is a significant variation in this indicator. It was found that in the same MDF, the coverage of the fibres with UF resin is between 42 and 94%. However, the uneven distribution contributing to the resin extraction is that UF resin is readily hydrolyzed in acidic and humid conditions. In the general case, hydrolysis joins hydroxyl groups at the expense of breaking bonds in materials. In UF resin, the methylene and methylene ester bonds are broken. It should be emphasized that hemicelluloses and cellulose are also susceptible to hydrolysis and concomitant resin extraction processes.

Hydrolysis with water at a temperature of 40 to 100° C and a duration of 2 to 6 hours was used in various studies. Hydrolysis in autoclaves at a pressure of 0.2 to 1.1 MPa, temperatures in the range of 120 to 180°C, was also applied, reducing the processing time to about 5 minutes. The fastest method for hydrolysis is the use of boiling with chemical reagents such as sodium hydroxide (NaOH), sodium sulfite (Na_2SO_3), carboxylic acid (COOH), sulfuric acid (H_2SO_4) and others. In these variants, the process duration is reduced to 1 ÷ 3 min (Lubis, M.A.R. et al. 2021). Due to the nature of the present work, the hydrolysis methods used will not be discussed in more detail here. Still, attention will be focused on the properties of pulp and the panels manufactured by different resin extraction methods.

In a study on the recycling of MDF by hydrolysis without chemical reagents, the effect of hydrothermal treatment temperature was investigated (Moezzipour, B. et al. 2017). In this study, three hydrothermal treatment temperatures were applied - 105, 125 and 150° C, and the duration at each temperature were 150 minutes. An analysis of the chemical composition of the fibres recycled by hydrolysis has shown that they have a lower content of lignin and hemicelluloses than natural fibres. As the processing temperature increases, a decrease in the range of these components is observed. In hemicelluloses, there is a decrease of 12% and lignin by 35%. A relatively significant reduction in the amounts of these wood components is observed when the tensile temperature increases from 125 to 150° C. It has been found that resin curing is slower when mixed with recycled fibres than with recycled fibres. Natural ones. Increasing the hydrothermal treatment temperature further prolongs the polymerization time of UF resin mixed with recycled fibres. The delay in curing at a recycling temperature of 150 ° C and natural fibres is 1.7 times. That is explained by the release of ammonia and other alkaline products in the recycling process by hydrolysis, which leads to an increase in the acid mass factor and a delay in the polymerization process of UF resin.

Regarding the swelling in the thickness of the panels, significant deterioration was found in the boards of recycled fibres. The same trend is observed in the bending strength of the panels. However, the overall decline with increasing temperature in recycled fiberboards is about 7%. The study's general conclusion is that it is not very justified to use recycling without chemical reagents to produce panels only from this type of fibre. These panels show inferior properties compared to panels fabricated from natural fibres. Due to the delay in the hardening of the resin, the time for hot pressing should be increased.

Of interest is a study in which electrolysis was performed (Moezzipour, B. et al. 2018). Hydrolysis is also essential for comparative analysis. Industrially produced MDF was used, which was crushed with a hammer mill. The hydrolysis was carried out by steaming for 150 minutes at a temperature of 105 ° C and a pressure of 0.4 MPa. For electrolysis, the crushed MDF is immersed in warm water for about 30 minutes and then mixed with electrolyte (saltwater). In the analysis of the physical and mechanical properties of the panels, it was found that the best (low) values of water absorption and thickness swelling are the panels manufactured from natural fibres. Immediately after that is the panel with hydrolysis and natural fibres (50:50), followed by the panels manufactured from fibres after 2 min. It was found that the panels fabricated from recycled fibres by electrolysis for 5 min have higher values of water absorption and swelling than the board fabricated after hydrothermal treatment. An analysis of formaldehyde emissions showed that recycled fiberboards had lower formaldehyde emissions. That is explained by the presence of traces of urea in them, which further absorb some formaldehyde. The overall conclusion from this study is that recycling after electrolysis is more appropriate than that hydrolysis. Particular attention should be paid to the regime factors in electrolysis. However, the main drawback of the study is that no economic assessment and analysis of the applicability of the methods used in industrial conditions has been made. In the general case, using a hydrothermal treatment for 150 minutes (hydrolysis) or electrolysis will lead to a significant increase in the cost of the production process. However, in this way, quality boards with formaldehyde emissions can be obtained even lower than those using natural fibres.

Another study (Lubis, M. A. et al. 2018) examined the influence of the content of recycled fibres in MDF on their properties.

Waste MDF is subjected to pre-treatment by hydrolysis, after which a hammer mill and a disk refiner are used for refining. The parameters of the fibres obtained through these two devices are compared. Panels with UF resin were produced with the participation of 0, 5, 10, 20, 30, 50 and 100% recycled fibres. It has been found that, regardless of the secondary refining method, all recycled fibres have shorter fibre lengths and a more significant amount of cut wood fibres. As a result of the presence of UF resin in all recycled fibres, the presence of nitrogen is detected. It has been found that secondary refining with disk mills increases the proportion of cut fibres compared to those manufactured with hammer mills.

CONCLUSIONS

Regardless of how the recycling occurred, the fabricated panels with recycled fibres have worse physical and mechanical properties than the MDF fabricated with natural ones. A great advantage in recycling with the extraction of binders is that the manufactured fibreboard panels have lower formaldehyde emissions. That is due to past processes and residual products from the hydrolysis of resins. In the reviewed studies with the application of hydrolysis, the issues of optimal content of recycled fibres in the panels remain debatable. Most such studies have not evaluated the feasibility of industrial applications. In general, it has been found that it is more appropriate to carry out secondary refining on hammer mills than disk mills in the case of hydrolysis. That, however, again leaves open the question of the industrial applicability of these methods.

Another option for extracting binders is electrolysis. With that recycling, MDF panels can be fabricated with better properties than hydrolysis, and the low formaldehyde emissions are maintained. But here, too, the question remains about the industrial applicability of the methods given the final cost of production. Despite the many problems, the numerous studies on MDF recycling prerequisites that this will soon become a well-established industrial practice.

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REFERENCES

AHMADI, M. AND MOEZZIPOUR, B. 2019. Thermal Stability of Wood Fibers Produced from Recycled Medium Density Fiberboards. DRVNA INDUSTRIJA, 70(2), pp. 149–155.

ANTOV, P. AND SAVOV, V. 2019. Possibilities for Manufacturing Eco-friendly Medium Density Fibreboards from Recycled Fibres – a Review. Proceedings of 30th International Conference on Wood Science and Technology - ICWST 2019 "IMPLEMENTATION OF WOOD SCIENCE IN WOODWORKING SECTOR" & 70th Anniversary of Drvna industrija Journal, 12th – 13th December, Zagreb, Croatia, pp. 18-24.

ATHANASSIADOU, E., MARKESSINI, C. AND TSIANTZI, S. 2015. Industrial amino adhesives satisfying stringent formaldehyde limits. In 2015 Melamine Conference, 15–16 November 2015, Dubai, available at: http://www.chimarhellas.com/wp-content/uploads/2016/03/CHIMAR-ELLAS-DUBAI.pdf

BÜTÜN BUSCHALSKY, F.Y., MAI, C. 2021. Repeated thermo-hydrolytic disintegration of medium density fibreboards (MDF) for the production of new MDF. (2021). Eur. J. Wood Prod. 79, pp. 1451–1459 (2021). DOI: 10.1007/s00107-021-01739-6.

HAGEL, S., SAAKE, B. 2020. Fractionation of Waste MDF by Steam Refining. Molecules, 25, 2165. DOI: 10.3390/molecules25092165.

HAGEL, S., JOY, J., CICALA, G., SAAKE, B. 2021. Recycling of Waste MDF by Steam Refining: Evaluation of Fiber and Paper Strength Properties. Waste and Biomass Valorization, 12, pp. 5701–5713. DOI: /10.1007/s12649-021-01391-4.

HAMEED, M.; BEHN, C.; ROFFAEL, E. AND DIX, B. 2005. Water retention capacity of recycling chips and chips derived directly from wood. European Journal of Wood and Wood Products.

HUI, W., XIANG-MING, W., ALPHA, B., JUN, S. 2014. Recycling wood composite panels: characterizing recycled materials. BioResources.

IHNÁT, V.; LÜBKE, H.; RUSS, A.; BORŮVKA, V. 2017. Waste agglomerated wood materials as a secondary raw material for chipboards and fibreboards. Part I. preparation and characterization of wood chips in terms of their reuse, Wood Research.

IRLE, M., PRIVAT, F., COURER, L., BELLONCLE, CH., BONNIN. E., CHATALA, B. 2019. Advanced recycling of post-consumer solid wood and MDF. Wood Materials Science and Engineering, 14(1), pp. 19–23. DOI: 10.1080/ 17480272.2018.1427144.

IŽDINSKÝ, J., VIDHOLDOVÁ, Z., REINPRECHT, L. 2020. Particleboards from Recycled Wood. Forests 11, 1166; DOI: 10.3390/f11111166.

KHARAZIPOUR A.; KÜES U. 2007. Recycling of wood composites and solid wood products. In: Wood production, wood technology, and biotechnological impacts. Universitätsverlag Göttingen, Germany.

KIM, M.H. AND SONG, H.B. 2014. Analysis of the global warming potential for wood waste recycling systems. Journal of Cleaner Production 69, 199e207. https://doi.org/10.1016/ j.jclepro.2014.01.039.

KUTNAR, A. AND BURNARD, M. D. 2014. The past, present and future of EU wood adhesive research and market. In Proc. of the International Conference on Wood Adhesives 2014, 9–11 October 2014, Toronto, Canada, available at: http://www.forestprod.org/ckfinder/userfiles/files/akutnar_08102013.pdf.

LUBIS, M. A. R., HONG, M. K., PARK, B. D., LEE, S. M. 2018. Effects of recycled fiber content on the properties of medium density fiberboard. European Journal of Wood and Wood Products,. DOI: 10.1007/s00107-018-1326-8.

LUBIS, M. A. R., MANOHAR, S. Y., LAKSANA, R. P. B., FATRIASARI, W., ISMAYATI, M., FALAH, F., SOLIHAT, N. N., SARI, F. P., HIDAYAT, W. 2021. The Removal of Cured Urea-Formaldehyde Adhesive Towards Sustainable Medium Density Fiberboard Production: A Review. Journal Silva Lestari, 9(1). DOI: 10.23960/jsl1923-44.

LYKIDIS C.; GRIGORIOU A. 2008. Hydrothermal recycling of waste and performance of the recycled wooden particleboards. Waste Management.

MANTANIS. G. I., ATHANASSIADOU, E., NAKOS, P., COUTINHO, A. 2004. A New Process for Recycling Waste Fiberboards. Proceedings of the 2nd European COST E31 Conference, Rogla, Slovenia.

MANTANIS, G. I., ATHANASSIADOU, E.T., BARBU, M.C., WIJNENDAELE, K. 2017. Adhesive systems used in the European particleboard, MDF and OSB industries, Wood Materials Science and Engineering, 13 (2), pp. 104–116. DOI:10.1080/17480272.2017.1396622.

MICHANICKL, A. AND BOEHME, C. 1995. Process for recovering chips and fibres from residues of timberderived materials, old pieces of furniture, production residues, waste and other timber-containing materials. European patent, EP 0 697 941 B1.

MICHANICKI, A. 1997. Recovery of fibers and particles from wood-based products. In: Proceedings of the Forest Products Society Conference on Use of Recycled Wood and Paper in Building Applications. Madison, USA.

MITCHELL, A. AND STEVENS, G. 2009. A life cycle assessment of closed loop MDF recycling using the microrelease process to produce recycled wood fibre from MDF waste. Final report of WRAP project MDD005 (ISBN: 1-84405-417-9), September 2009.

MOEZZIPOUR, B., AHMADI, M., ABDOLKHANI, A., DOOSTHOSEINI, K. 2017. Chemical changes of wood fibers after hydrothermal recycling of MDF waste. Journal of Indian Academic of Wood Science 14(2), pp. 133–138. DOI: 10.1007/s13196-017-0198-6.

MOEZZIPOUR, B., ABDOLKHANI, A., DOOST-HOSEINI, K., RAMAZANI, S. A. A., TARMIAN, AS. 2018. Practical properties and formaldehyde emission of medium density fiberboards (MDFs) recycled by electrical method. European Journal of Wood and Wood Products, 76, pp.1287–1294. DOI: 0.1007/s00107-018-1291-2.

NURYAWAN, A., RISNASARI, I., POHAN, A.P., HUSNA, A. U., NASUTION, T. I., BANUREA, R., HARTINI, K., S. 2020. Properties of fibreboard (FBs) and recycle fibreboard (rFBs) and analysis of their wastage after recycling. IOP Conference Series: Materials Science and Engineering 935, 012060. DOI: 10.1088/1757-899X/935/1/012060.

ORMONDROYD, G. A., ELIAS, R. M., CURLING, S. F. 2017. MDF Recovery: Recycled MDF technologies for routed and laminated applications. Poster Presentation. ResearcGate.

ROFFAEL, E. (2002). Method for use of recycled lignocellulosic composite materials, US Patent Application #20020153107A1.

ROFFAEL, E. AND KRAFT, R. 2004. For the thermohydrolytic degradation of UF resins in chipboard. Holz als Rohund Werkstoff.

SALA, C. M., KOWALUK, GR. 2020. The influence of Defibration Pressure and Fibres drying parameters on the Properties of HDF Made with Recovered Fibres. Annals of Warsaw University of Life Sciences, 111, pp. 143–159.

SANDBERG, D. 2016. Additives in wood products – Today and future developments. In Environmental footprints and eco-design of products and processes. Springer Science, Available at: https://www.diva-portal.org/smash/get/diva2:993130/FULLTEXT01.pdf. [Accessed 03. 2022].

FAO STAT. Forestry Production and Trade, [online] Available at: https://www.fao.org/faostat/en/#data/FO [Accessed 03. 2022]

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