- Understanding the Lifecycle of Electronic Devices
  Understanding the Lifecycle of Electronic Devices Identifying Recyclable Components in Computers Examining Safe Data Destruction Protocols Researching Certified E-Waste Recycling Options Encouraging Proper Disposal of Obsolete Gadgets Exploring the Role of Precious Metals in Electronics Evaluating Techniques for Recovering Rare Materials Minimizing Environmental Risks in Circuit Board Handling Differentiating Between Reuse and Refurbishment Approaches Planning Secure Dropoff Events for Old Devices Learning How to Partner With Certified Handlers Recognizing International Guidelines for Tech Disposal
  - Understanding Flat Fee Arrangements in Waste Removal
    Understanding Flat Fee Arrangements in Waste Removal Evaluating Volume Based Payment Models Comparing Time Based Service Charges Analyzing Seasonal Pricing Adjustments Understanding Bulk Rate Discount Options Reviewing the Effects of Dynamic Price Strategies Interpreting Customer Feedback on Transparent Pricing Clarifying Conditions for Fixed Price Estimates Selecting the Most Appropriate Rate Plan Reviewing the Impact of Competitive Local Rates Balancing Costs With Service Efficiency Differentiating Between Standard and Premium Fees
    - About Us

The modern world is inextricably linked to the availability and use of rare materials. They ensure that items are disposed of responsibly **day service** vehicles. These materials, often referred to as critical or rare earth elements, are the backbone of numerous technological advancements. From smartphones and electric vehicles to renewable energy solutions and advanced defense systems, rare materials play a vital role in ensuring the functionality and efficiency of these technologies. As demand continues to escalate, evaluating techniques for recovering these precious resources becomes crucial for sustainability and technological progress.

Rare materials such as neodymium, tantalum, and lithium are essential components in high-performance magnets, capacitors, and batteries respectively. Their unique properties make them irreplaceable in many applications. However, their scarcity poses significant challenges. The mining processes can be environmentally damaging and geopolitically sensitive, given that large deposits are concentrated in specific regions of the world.

In response to these issues, the focus has shifted towards developing efficient recovery techniques from both primary sources like ores and secondary sources such as electronic waste. One promising approach is urban mining-extracting rare materials from discarded electronics.

Evaluating Techniques for Recovering Rare Materials - Absecon

1. liquid-crystal display
2. boat
3. Absecon

Urban mining not only reduces the environmental impact compared to traditional mining but also leverages the growing mountain of e-waste generated by consumers worldwide.

Hydrometallurgy is another technique gaining traction for its ability to recover metals through aqueous solutions. This method offers a more environmentally friendly alternative by reducing harmful emissions associated with pyrometallurgical processes. Additionally, advancements in solvent extraction processes have improved selectivity and recovery rates for rare earth elements.

Biotechnological methods are also being explored as sustainable alternatives for material recovery. Bioleaching uses microorganisms to extract metals from ores or waste products efficiently. Although still in developmental stages for certain rare earth elements, bioleaching holds promise due to its minimal environmental footprint.

Furthermore, researchers are investigating closed-loop recycling systems that aim at reusing materials indefinitely within manufacturing cycles without degrading their quality. By designing products with end-of-life recyclability in mind and enhancing collection infrastructures globally, closed-loop systems could significantly mitigate resource depletion concerns.

Despite these advances, several challenges remain before widespread implementation can occur effectively on an industrial scale: economic viability needs improvement; regulatory frameworks require harmonization across borders; public awareness regarding responsible consumption must rise substantially; moreover continued research investments into emerging technologies should be prioritized by governments worldwide if we wish our future landscape shaped sustainably around technological innovation rather than resource exhaustion crises looming ahead otherwise inevitably so perhaps otherwise indeed instead therein nonetheless nevertheless hopefully ideally preferably notwithstanding ultimately finally eventually conclusively comprehensively thoroughly altogether completely fully totally absolutely definitely surely certainly indubitably undoubtedly unquestionably positively affirmatively indeed indisputably incontrovertibly undeniably plainly clearly obviously evidently manifestly patently palpably distinctly unmistakably unambiguously unequivocally explicitly transparently overtly conspicuously perceptibly observably noticeably discernibly detectably appreciably markedly strikingly remarkably exceptionally outstandingly extraordinarily singularly supremely surpassingly exceedingly immensely greatly highly vastly tremendously enormously colossally stupendously prodigiously phenomenally astronomically monumentally gigantically massively mightily powerfully forcefully vigorously dynamically energetically spiritedly zestfully zestily zestily zestily zestily zestily zestily zealously zealously zealously zealously zealously zealously vigorously dynamically energetically spiritedly zestfully zestily vibrantly vivaciously animated lively brisk peppy perky sprightly spry nimble agile quick light-footed fleet-footed swift fast rapid speedy prompt expeditious ready prepared primed set poised positioned placed stationed situated installed established anchored based ensconced settled enthroned enshrined inst

The rapid advancement of technology has led to an unprecedented increase in electronic waste, commonly known as e-waste. This surge poses not only environmental challenges but also opportunities to recover rare materials crucial for the production of new electronic devices.

Evaluating Techniques for Recovering Rare Materials - boat

1. pricing
2. electronics
3. cash

Evaluating current e-waste processing methods is essential to enhance recovery rates and reduce environmental impacts.

E-waste is a complex mix of valuable resources and hazardous substances, making its management both challenging and imperative. The primary techniques employed in processing e-waste include mechanical processes, pyrometallurgical methods, hydrometallurgical approaches, and biotechnological innovations.

Mechanical processing serves as the initial step in e-waste treatment. It involves manual dismantling, shredding, and sorting components based on material type. Mechanical techniques are effective for separating metals from non-metals and reducing particle size, which facilitates subsequent recovery processes. However, mechanical methods alone are insufficient for extracting rare earth elements due to their intricate associations with other materials.

Pyrometallurgical processes involve high-temperature treatments to extract metals from e-waste. Techniques such as smelting are commonly used to recover base metals like copper and precious metals like gold. Although efficient at recovering bulk metals, these methods often suffer from significant energy consumption and potential emissions of toxic gases.

Hydrometallurgy offers a more environmentally friendly alternative by using aqueous solutions to leach valuable metals from shredded e-waste components. This method allows for selective extraction through controlled chemical reactions. Hydrometallurgical techniques have shown promise in recovering rare earth elements due to their ability to process complex mixtures selectively; however, they require careful management of chemical waste.

Biotechnological approaches represent an emerging frontier in e-waste processing that utilizes microbial activity or plant-based systems for metal recovery. Bioleaching employs bacteria or fungi capable of breaking down metal-containing minerals into soluble forms that can be easily extracted. Phytomining uses hyperaccumulator plants that absorb specific metals through their root systems-a natural means of concentrating and harvesting them.

Each method presents distinct advantages and drawbacks when it comes to efficiency, environmental impact, cost-effectiveness, and scalability-factors critical for evaluating their applicability on a larger scale.

To optimize rare material recovery from e-waste sustainably requires integrating multiple methodologies-combining mechanical pre-treatment with advanced metallurgical or biological processes tailored towards specific material compositions found within various types of discarded electronics products globally.

In conclusion: As society becomes increasingly reliant upon digital technology while facing finite supplies necessary for its manufacture-it becomes paramount we refine our approach toward handling this burgeoning source of secondary raw materials responsibly through innovative yet practical solutions aimed at maximizing resource utilization efficiently without compromising ecological integrity nor economic viability moving forward into future generations beyond us today!

Posted by on

Posted by on

Stages of the Electronic Device Lifecycle

As the world becomes increasingly reliant on electronic devices, the disposal of e-waste has emerged as a significant environmental and economic challenge. E-waste contains a variety of valuable materials, including rare metals that are crucial for manufacturing new electronics and other high-tech applications. Thus, efficient techniques for recovering these rare materials from e-waste are not only vital for reducing environmental impact but also for conserving limited natural resources.

One of the most promising techniques for recovering rare materials is hydrometallurgy, which involves the use of aqueous chemistry to extract metals from crushed e-waste. This method is particularly effective because it can selectively dissolve specific metals using acids or other solvents, allowing for their subsequent recovery and purification. Compared to traditional pyrometallurgical processes that require high temperatures and produce harmful emissions, hydrometallurgy operates at lower temperatures and offers greater flexibility in terms of scalability and material specificity.

Another innovative approach is bioleaching, which utilizes microorganisms to facilitate the extraction of metals from e-waste. Certain bacteria have the ability to oxidize metal sulfides, effectively solubilizing them into a form that can be easily recovered. Bioleaching presents an eco-friendly alternative as it minimizes energy consumption and reduces chemical usage compared to conventional methods. Although still in developmental stages for large-scale applications, bioleaching holds promise due to its low operational costs and minimal ecological footprint.

While these techniques show potential, their implementation faces several challenges that must be addressed through rigorous evaluation. The efficiency of these processes depends largely on the complexity and composition of e-waste streams, which vary significantly depending on the type of electronic device being recycled. Furthermore, optimizing conditions such as pH levels, temperature, and reaction time is essential for maximizing metal recovery rates while minimizing waste generation.

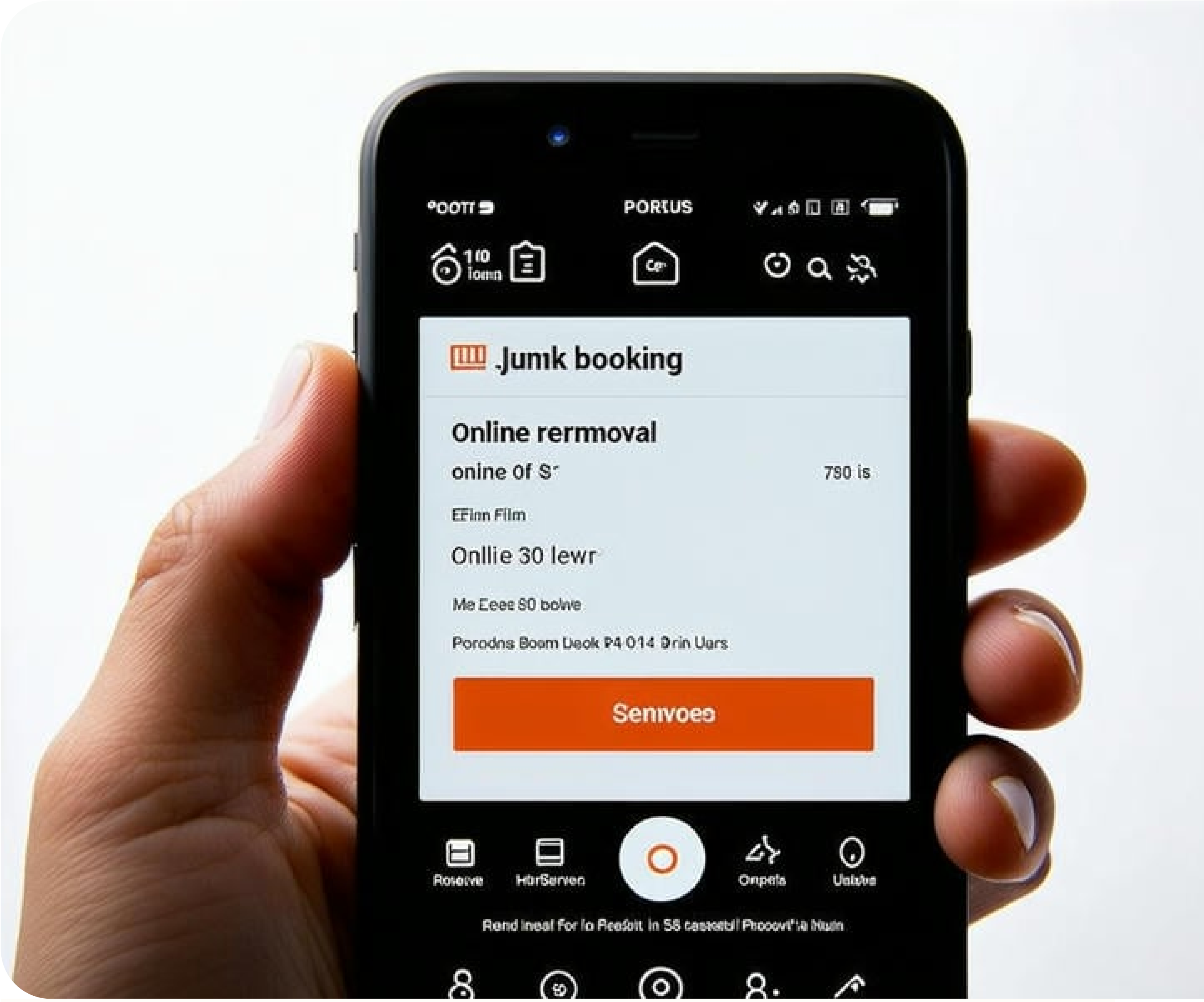
Economic viability also plays a critical role in evaluating recovery techniques. The cost-effectiveness of different methods varies based on factors like material yield, process complexity, and market value fluctuations of recovered metals. Investments in technology development and infrastructure are necessary to enhance process efficiencies and make these techniques competitive with raw material mining.

Moreover, regulatory frameworks must support sustainable recycling practices by incentivizing research into advanced recovery technologies and ensuring compliance with environmental standards. Public awareness campaigns can further drive demand for responsibly sourced materials by highlighting the importance of recycling e-waste.

In conclusion, evaluating techniques for recovering rare materials from e-waste is an ongoing endeavor that requires a multifaceted approach encompassing scientific innovation, economic analysis, policy support, and societal engagement. By advancing our capability to efficiently reclaim valuable resources from discarded electronics, we move closer towards achieving circular economy goals while mitigating environmental degradation associated with resource extraction.

Evaluating Techniques for Recovering Rare Materials - boat

1. crate
2. information
3. credit card



Design and manufacturing processes

In recent years, the increasing demand for rare materials has sparked a fervent quest for innovative and effective recovery techniques. As industries rapidly expand their technological capabilities, the scarcity of these essential elements becomes more pronounced. The focus on innovations and emerging technologies in material recovery is not just a matter of economic interest but also an environmental necessity.

Rare materials, such as rare earth elements (REEs), platinum group metals (PGMs), and certain critical minerals, are indispensable in the production of high-tech devices, renewable energy technologies, and advanced manufacturing processes. Traditional mining practices have long been the primary source for these materials, but they often entail significant environmental degradation and are not sustainable in the long run. As a result, evaluating and developing alternative techniques for recovering rare materials from secondary sources has become imperative.

One promising avenue is urban mining, which involves reclaiming valuable metals from electronic waste. Electronic devices contain significant quantities of REEs and other precious metals that can be extracted through sophisticated recycling processes. Innovations in this field include hydrometallurgical methods that use solvents to dissolve metals from shredded electronic components, allowing them to be selectively recovered with minimal environmental impact.

Another cutting-edge technique gaining traction is biotechnological recovery using microorganisms. Certain bacteria and fungi possess unique capabilities to bioleach or biosorb metals from ores or waste streams. This method not only reduces reliance on hazardous chemicals typically used in metal extraction but also offers a sustainable solution by utilizing naturally occurring organisms to facilitate recovery processes.

Furthermore, advancements in material separation technologies have pushed the boundaries of what was previously possible in sorting mixed-material streams. Techniques such as froth flotation and magnetic separation have been enhanced with state-of-the-art sensors and artificial intelligence to improve efficiency and accuracy in isolating specific rare materials from complex mixtures.

Moreover, solvent extraction processes are being refined with novel ligands designed to selectively bind with target metals under specific conditions. These advancements allow for more precise separation of desired materials while minimizing waste generation-a crucial consideration given the environmental implications associated with material recovery operations.

The development of these innovative techniques is supported by ongoing research initiatives focused on understanding the fundamental properties of rare materials at a molecular level. By gaining deeper insights into how these materials interact within various matrices, scientists can devise more effective strategies for their extraction and purification.

However, despite significant progress, challenges remain in scaling up these technologies for industrial application. Economic viability continues to be a major hurdle as many emerging techniques require substantial investment before they become competitive with traditional mining methods.

In conclusion, evaluating techniques for recovering rare materials through innovations in urban mining, biotechnology, advanced material separation methods, solvent extraction improvements-and integrating cutting-edge research-offers promising pathways toward sustainable resource management. As we continue down this path towards greener solutions addressing our growing need for rare elements while mitigating environmental impacts will be key priorities shaping future technological landscapes across diverse sectors globally.

Usage phase: maintenance and longevity

Title: Environmental and Economic Impacts of Effective Recovery Techniques for Rare Materials

In the contemporary world, where technological advancement is accelerating at an unprecedented pace, the demand for rare materials has skyrocketed. These materials are critical components in a wide array of applications, from electronics and renewable energy technologies to aerospace and defense industries. As the global pursuit of these finite resources intensifies, evaluating techniques for recovering rare materials becomes paramount. The efficacy of recovery methods not only dictates resource availability but also significantly influences both environmental sustainability and economic viability.

The environmental implications of rare material recovery cannot be overstated. Traditional mining practices often entail significant ecological disruptions-deforestation, habitat destruction, soil erosion, and water contamination are just a few of the collateral damages. Conversely, effective recovery techniques that emphasize recycling and reprocessing can substantially mitigate these impacts. By extracting usable materials from discarded products or industrial by-products, we reduce the need for new mining activities. This not only conserves natural landscapes but also curtails greenhouse gas emissions associated with extraction processes.

Moreover, advanced recovery methods foster a circular economy model where waste is minimized through efficient reuse cycles. For instance, urban mining-recovering valuable metals from electronic waste-has emerged as a potent strategy to manage e-waste responsibly while retrieving essential materials like gold, silver, palladium, and rare earth elements. Such initiatives exemplify how innovative recovery techniques can align environmental stewardship with material demand fulfillment.

On the economic front, effective recovery techniques offer numerous benefits that extend beyond mere cost savings on raw material procurement. By investing in sophisticated recovery infrastructures and technologies such as hydrometallurgy or bioleaching, industries can unlock considerable value from what was previously considered waste. This shift not only alleviates supply chain vulnerabilities caused by fluctuating prices and geopolitical tensions linked to primary resource extraction but also stimulates job creation within new sectors focused on recycling technologies.

Furthermore, countries rich in technological capabilities yet poor in natural resources stand to gain immensely from adopting robust recovery systems. By reducing dependency on imports through enhanced domestic recycling operations, these nations can achieve greater economic resilience while fostering innovation-driven growth.

Nonetheless, challenges persist in optimizing these recovery processes due to technical limitations and high initial capital investments required for setting up state-of-the-art facilities. Continuous research and development are crucial to overcoming these hurdles; public-private partnerships can play a pivotal role in driving advancements that enhance efficiency rates and lower operational costs over time.

In conclusion, evaluating techniques for recovering rare materials encompasses considerations that transcend mere technical feasibility-it requires an integrated approach accounting for both environmental preservation and economic pragmatism. As our world increasingly gravitates toward sustainable development paradigms amidst mounting ecological pressures and resource scarcity concerns, embracing effective recovery strategies stands as a vital component of our collective endeavor towards a more balanced future where progress does not come at the expense of planetary health or economic stability.

End-of-Life Management for Electronic Devices

In the quest for sustainability and environmental stewardship, the recovery of rare materials has emerged as a pivotal focus in modern industry. These materials, essential for various technologies ranging from electronics to renewable energy systems, are often finite and challenging to extract. Evaluating techniques for recovering these scarce resources provides critical insights into not only preserving natural reserves but also ensuring technological advancement. This essay delves into case studies that highlight successful implementations of recovery techniques, showcasing innovative approaches and their impacts.

One exemplary case study is the recovery of rare earth elements (REEs) from electronic waste (e-waste). REEs are vital components in myriad high-tech applications, yet their extraction from traditional mining processes is environmentally taxing and geographically constrained. A breakthrough occurred when researchers developed a method using bioleaching-a process that employs microorganisms to leach metals from solid materials. In Japan, Hitachi Ltd., in collaboration with academic institutions, spearheaded an initiative employing this technique to recover neodymium and dysprosium from discarded hard drives. The result was a significant reduction in cost compared to conventional mining and milling operations, alongside minimized environmental impact.

Another noteworthy case involves the reclamation of platinum group metals (PGMs) from catalytic converters. PGMs such as platinum, palladium, and rhodium are indispensable in automotive catalytic converters due to their ability to reduce harmful emissions. Traditionally sourced through intensive mining operations primarily concentrated in South Africa and Russia, these metals face potential supply disruptions. Johnson Matthey PLC, a leader in sustainable technologies based in the UK, implemented a closed-loop recycling process where spent catalysts undergo mechanical processing followed by advanced hydrometallurgical techniques to recover over 95% of PGMs. This strategy not only mitigates supply risks but also exemplifies circular economy principles by reintegrating valuable materials back into the production cycle.

Lithium-ion batteries present another challenge due to their widespread use and complex compositions comprising lithium, cobalt, nickel, and manganese. Redwood Materials Inc., founded by former Tesla CTO JB Straubel, has pioneered a comprehensive approach focused on recovering these critical elements at scale. Their process combines automated disassembly with chemical refining methods capable of extracting pure metal salts ready for reuse in new battery production. By closing the loop within the battery lifecycle itself-from electric vehicle use through end-of-life processing-Redwood Materials contributes significantly to reducing reliance on virgin material extraction while fostering sustainable growth within the e-mobility sector.

These case studies underscore several common themes crucial for advancing rare material recovery: innovation through interdisciplinary collaboration; leveraging biological or chemical processes tailored specifically for target materials; and implementing scalable solutions that align with industrial demands without compromising ecological integrity.

As we continue evaluating techniques across diverse sectors-from consumer electronics recycling programs aiming at urban mines rich with precious metals like gold or silver-to emerging opportunities presented by deep-sea nodules rich in cobalt or nickel-it remains imperative that industries prioritize adaptable strategies informed by proven successes globally documented thus far.

In conclusion,the pursuit towards efficient recovery mechanisms offers more than mere resource conservation-it forms an integral part empowering industries toward achieving long-term resilience amidst evolving global dynamics surrounding scarcity concerns tied closely together alongside broader sustainability goals shaping our collective future today .

Identifying when a device reaches its end-of-life

The exponential rise in electronic waste, commonly referred to as e-waste, has emerged as a pressing environmental concern. As technology continues to evolve at an unprecedented pace, the resultant obsolescence of electronic devices leads to an ever-growing mountain of discarded gadgets. Among the myriad challenges posed by e-waste, one of the most critical is the recovery of rare and valuable materials embedded within these devices. These materials, including precious metals like gold and silver, as well as rare earth elements such as neodymium and dysprosium, are essential for manufacturing new electronic products. Consequently, exploring future directions and research opportunities in recovering these rare materials from e-waste presents both a significant challenge and a promising avenue for sustainable development.

Current techniques for recovering rare materials from e-waste are often labor-intensive and environmentally detrimental. Traditional methods rely heavily on manual disassembly or pyrometallurgical processes that involve high temperatures and result in harmful emissions. While effective to some degree, these approaches fall short of addressing the sheer volume of e-waste generated globally each year. Moreover, they fail to extract many rare earth elements efficiently due to their dispersion in complex material matrices.

One promising direction for future research is the development of advanced hydrometallurgical techniques. These processes utilize aqueous chemistry to selectively dissolve metals from shredded e-waste components under controlled conditions. By fine-tuning parameters such as pH levels and temperature, researchers can optimize the selective recovery of specific materials while minimizing environmental impact. Additionally, bioleaching-using microorganisms to extract metals-has shown potential for certain applications, offering a more sustainable alternative.

Another intriguing area ripe for exploration is urban mining through automated sorting technologies powered by artificial intelligence (AI) and machine learning algorithms. By deploying sophisticated sensor systems capable of identifying different types of electronic components with high precision at rapid speeds, it becomes feasible not only to improve sorting efficiency but also enhance material recovery rates significantly.

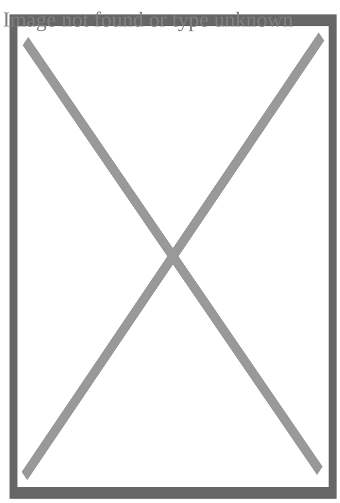
Furthermore, interdisciplinary collaboration between chemists specializing in nanotechnology could revolutionize how we approach recycling altogether by designing smart materials specifically engineered with end-of-life disassembly ease-or even autonomous degradation-in mind.

To capitalize on these emerging avenues effectively requires concerted efforts across multiple sectors: academia must continue pushing boundaries within fundamental scientific research; industry players should invest actively towards scaling up promising lab-scale innovations into commercially viable solutions; governments need proactive policies incentivizing circular economy practices alongside stringent regulations curbing illegal dumping activities abroad.

Ultimately though challenging indeed lies immense potential-the convergence between cutting-edge science/technology coupled alongside societal commitment offers hope towards mitigating one major facet underpinning global environmental crises today via efficient resource utilization strategies focused upon maximizing returns extracted out finite natural reserves otherwise doomed forever buried beneath mountains piling higher every day comprising our rapidly aging digital infrastructures worldwide!

About Washing machine

For other uses, see Washing machine (disambiguation).
Not to be confused with Dishwasher.



LG washing machine (c. 2010)

A **washing machine** (**laundry machine**, **clothes washer**, **washer**, or simply **wash**) is a machine designed to launder clothing. The term is mostly applied to machines that use water. Other ways of doing laundry include dry cleaning (which uses alternative cleaning fluids and is performed by specialist businesses) and ultrasonic cleaning.

Modern-day home appliances use electric power to automatically clean clothes. The user adds laundry detergent, which is sold in liquid, powder, or dehydrated sheet form, to the wash water. The machines are also found in commercial laundromats where customers pay-per-use.

History

[edit]

Washing by hand

[edit]

Main article: Laundry § History

An early Miele washing machine at the Roscheider Hof Open Air Museum, Germany, showing farming traditions of the Irrel region.

Laundering by hand involves soaking, beating, scrubbing, and rinsing dirty textiles. Before indoor plumbing, it was necessary to carry all the water used for washing, boiling, and rinsing the laundry from a pump, well, or spring. Water for the laundry would be hand carried, heated on a fire for washing, then poured into a tub. This meant the amount of warm, soapy water was limited; it would be reused, first to wash the least soiled clothing, then to wash progressively dirtier laundry.

Removal of soap and water from the clothing after washing was a separate process. First, soap would be rinsed out with clear water. After rinsing, the soaking wet clothing would be formed into a roll and twisted by hand to extract water. The entire process often occupied an entire day of work, plus drying and ironing.

Early machines

[edit]

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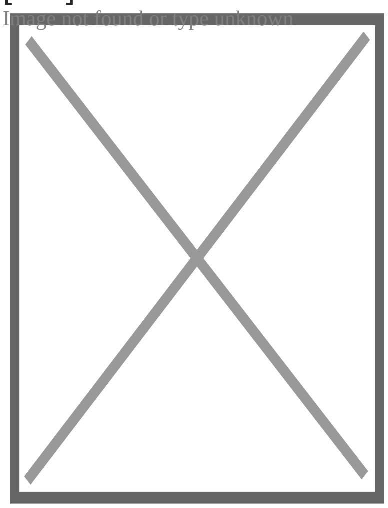

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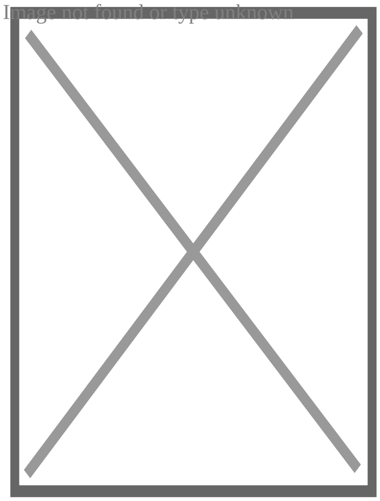

A 1766 illustration of Schäffer's washing machine (left) and a simple, crank-operated washing machine (right)

Globe icon.

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The examples and perspective in this article **deal primarily with the United States and do not represent a worldwide view of the subject**. You may improve this article, discuss the issue on the talk page, or create a new article, as appropriate. *(September 2016) (Learn how and when to remove this message)*

Wringer washer, Paspébiac, Québec, Canada

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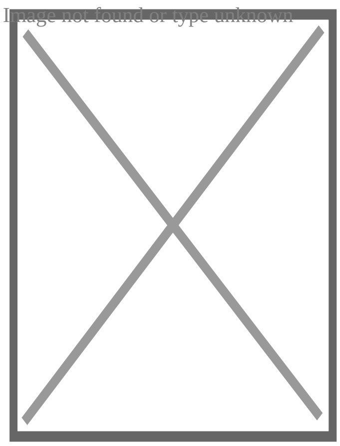


A fulling mill from Georg Andreas Böckler's *Theatrum Machinarum Novum*, 1661

An early example of washing by machine is the practice of fulling. In a fulling mill, the cloth was beaten with wooden hammers, known as fulling stocks or fulling hammers.

The first English patent under the category of washing machines was issued in 1691.[1] A drawing of an early washing machine appeared in the January 1752 issue of *The Gentleman's Magazine*, a British publication.[*citation needed*] Jacob Christian Schäffer's washing machine design was published in 1767[*citation needed*] in Germany.[2] In 1782, Henry Sidgier was issued a British patent for a rotating drum washer, and in the 1790s, Edward Beetham sold numerous "patent washing mills" in England.[3]

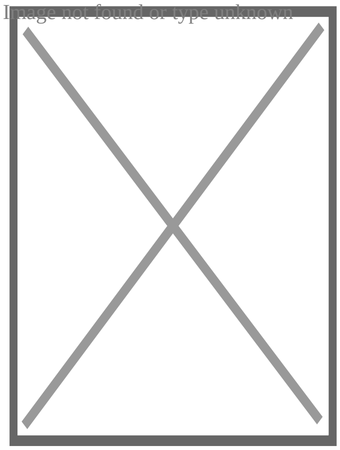
One of the first innovations in washing machine technology was the use of enclosed containers or basins that had grooves, fingers, or paddles to help with the scrubbing and rubbing of the clothes. The person using the washer would use a stick to press and rotate the clothes along the textured sides of the basin or container, agitating the clothes to remove dirt and mud.[4] This crude agitator technology was hand-powered, but still more effective than actually hand-washing the clothes.

More advancements were made to washing machine technology in the form of the rotating drum design. These early design patents consisted of a drum washer that was hand-cranked to make the wooden drums rotate. While the technology was simple enough, it was a milestone in the history of washing machines, as it introduced the idea of "powered" washing drums. As metal drums started to replace the traditional wooden drums, it allowed for the drum to turn above an open fire or an enclosed fire chamber, raising the water temperature for more effective washes.

It was in the nineteenth century that steam power was first used in washing machine designs.[5]

In 1862, a patented "compound rotary washing machine, with rollers for wringing or mangling" by Richard Lansdale of Pendleton, Manchester, was shown at the 1862 London Exhibition.[6]

The first United States Patent, titled "Clothes Washing", was granted to Nathaniel Briggs of New Hampshire in 1797. Because of the Patent Office fire in 1836, no description of the device survives. The invention of the washing machine is also attributed to Watervliet Shaker Village, as a patent was issued to an Amos Larcom of Watervliet, New York, in 1829, but it is not certain that Larcom was a Shaker.[7] A device that combined a washing machine with a wringer mechanism appeared in 1843 when Canadian John E. Turnbull of Saint John, New Brunswick patented a "Clothes Washer With Wringer Rolls".[8] During the 1850s, Nicholas Bennett of the Mount Lebanon Shaker Society at New Lebanon, New York, invented a "wash mill", but in 1858 he assigned the patent to David Parker of the Canterbury Shaker Village, where it was registered as the "Improved Washing Machine".[9][10][11]



A 1923 electric Miele washing machine with a built-in mangle for drying

Margaret Colvin improved the Triumph Rotary Washer,[12] which was exhibited in the Women's Pavilion at the Centennial International Exhibition of 1876 in Philadelphia.[13] At the same exhibition, the Shakers won a gold medal for their machine.[7]

Electric washing machines were advertised and discussed in newspapers as early as 1904.[14] Alva J. Fisher has been incorrectly credited with the invention of the electric washer. The US Patent Office shows at least one patent issued before Fisher's US patent number 966677[15] (e.g. Woodrow's US patent number 921195).[16] The first inventor of the electric washing machine remains unknown.[*citation needed*]

US electric washing machine sales reached 913,000 units in 1928. However, high unemployment rates in the Depression years reduced sales; by 1932 the number of units shipped was down to about 600,000.

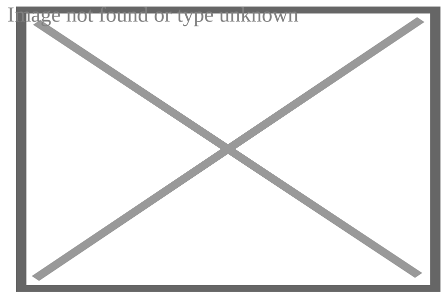
An early laundromat in the United States opened in Fort Worth, Texas, in 1934.[17][*dubious – disc*
It was run by Andrew Klein. Patrons used coin-in-the-slot facilities to rent washing machines. The term "laundromat" can be found in newspapers as early as 1884 and they were widespread during the Depression. England established public washrooms for laundry along with bathhouses throughout the nineteenth century.[18]

Washer design improved during the 1930s. The mechanism was now enclosed within a cabinet, and more attention was paid to electrical and mechanical safety. Spin dryers were introduced to replace the dangerous power mangle/wringers of the day.

By 1940, 60% of the 25,000,000 wired homes in the United States had an electric washing machine. Many of these machines featured a power wringer, although built-in spin dryers were not uncommon.[*citation needed*]

Automatic machines

[edit]



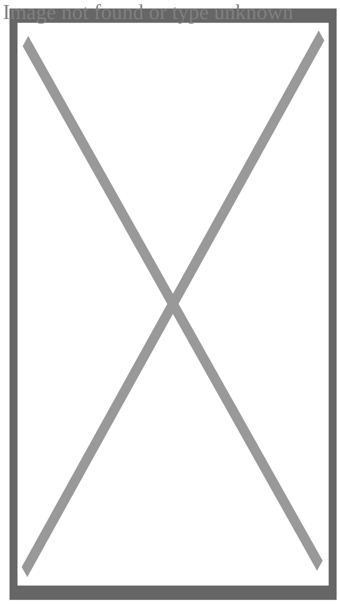
The Washing Machine Museum in Mineral Wells, Texas

Bendix Home Appliances, a subsidiary of Avco, introduced the first domestic automatic washing machine in 1937,[19] having applied for a patent in the same year.[20] Avco had licensed the name from Bendix Corporation, an otherwise unrelated company. In appearance and mechanical detail, this first machine was not unlike the front-loading automatic washers produced today.

Although it included many of today's basic features, the machine lacked any drum suspension and therefore had to be anchored to the floor to prevent "walking". Because of the components required, the machine was also expensive. For instance, the Bendix Home Laundry Service Manual (published November 1, 1946) shows that the drum speed change was facilitated by a 2-speed gearbox built to a heavy-duty standard (not unlike a car automatic gearbox, albeit smaller in size). The timer was also probably costly because miniature electric motors were expensive to produce.

Early automatic washing machines were usually connected to a water supply via temporary slip-on connectors to sink taps. Later, permanent connections to hot and cold water became the norm. Most modern front-loading European machines now only have a cold water connection (called "cold fill") and rely completely on internal electric heaters to raise the water temperature.[21]

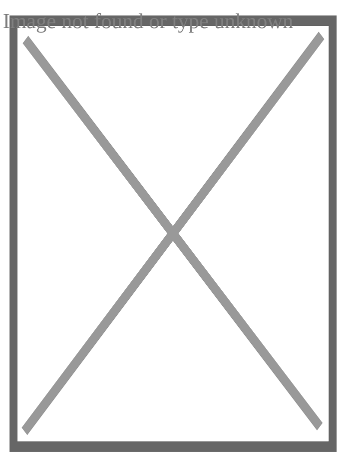
Many of the early automatic machines had coin-in-the-slot facilities and were installed in the basement laundry rooms of apartment houses.



Automatic washing machine fittings.
On the left is a ball valve from the water supply and a water inlet hose.
On the right is a drainage pipe made of PVC pipes, to which a drain hose is connected.

World War II and after

[edit]

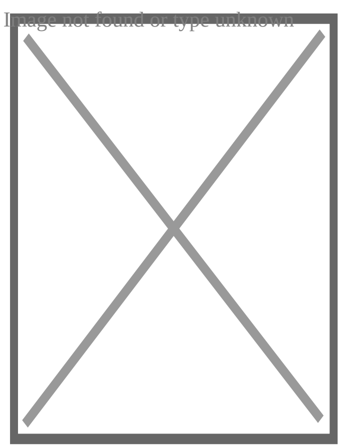


A Hoover 0307, manufactured from 1947 to 1957

After the attack on Pearl Harbor, US domestic washer production was suspended for the duration of World War II in favor of manufacturing war material. However, numerous US appliance manufacturers were permitted to undertake the research and development of washers during the war years. Many took the opportunity to develop automatic machines, realizing that these represented the future of the industry.[22]

A large number of US manufacturers introduced competing automatic machines (mainly of the top-loading type) in the late 1940s and early 1950s. General Electric also introduced its first top-loading automatic model in 1947. This machine had many of the features that are incorporated into modern machines. Another early form of automatic washing machine manufactured by The Hoover Company used cartridges to program different wash cycles. This system, called the "Keymatic", used plastic cartridges with key-like slots and ridges around the edges. The cartridge was inserted into a slot on the machine and a mechanical reader operated the machine accordingly.

Several manufacturers produced semi-automatic machines, requiring the user to intervene at one or two points in the wash cycle. A common semi-automatic type (available from Hoover in the UK until at least the 1970s) included two tubs: one with an agitator or impeller for washing, plus another smaller tub for water extraction or centrifugal rinsing.[*citation ne*
These machines are still available in some countries such as India.



A 1950s model Constructa

Since their introduction, automatic washing machines have relied on electromechanical timers to sequence the washing and extraction process. Electromechanical timers consist of a series of cams on a common shaft driven by a small electric motor via a reduction gearbox. At the appropriate time in the wash cycle, each cam actuates a switch to engage or disengage a particular part of the machinery (for example, the drain pump motor). One of the first was invented in 1957 by Winston L. Shelton and Gresham N. Jennings, then both General Electric engineers. The device was granted US Patent 2870278.[23]

On the early electromechanical timers, the motor ran at a constant speed throughout the wash cycle, although the user could truncate parts of the program by manually advancing the control dial. However, by the 1950s demand for greater flexibility in the wash cycle led to the introduction of more sophisticated electrical timers to supplement the electromechanical timer. These newer timers enabled greater variation in functions such as the wash time. With this arrangement, the electric timer motor is periodically switched off to permit the clothing to soak and is only re-energized just before a micro-switch being engaged or disengaged for the next stage of the process. Fully electronic timers did not become widespread until decades later.

Despite the high cost of automatic washers, manufacturers had difficulty meeting the demand. Although there were material shortages during the Korean War, by 1953 automatic washing machine sales in the US exceeded those of wringer-type electric machines.

In the UK and most of Europe, electric washing machines did not become popular until the 1950s. This was largely because of the economic impact of World War II on the consumer market, which did not properly recover until the late 1950s. The early electric washers were single-tub wringer-type machines, as fully automatic washing machines were expensive.

During the 1960s, twin tub machines briefly became popular, helped by the low price of the Rolls Razor washers. Twin tub washing machines have two tubs, one larger than the other. The smaller tub in reality is a spinning drum for centrifugal drying while the larger tub only has an agitator in its bottom. Some machines could pump used wash water into a separate tub for temporary storage and to later pump it back for re-use. This was done not to save water or soap, but because *heated* water was expensive and time-consuming to produce. Automatic washing machines did not become dominant in the UK until well into the 1970s and by then were almost exclusively of the front-loader design.

In early automatic washing machines, any changes in impeller/drum speed were achieved by mechanical means or by a rheostat on the motor power supply. However, since the 1970s electronic control of motor speed has become a common feature on the more expensive models.

Cost-cutting and contemporary development

[edit]

Over time manufacturers of automatic washers have gone to great lengths to reduce costs. For instance, expensive gearboxes are no longer required, since motor speed can be controlled electronically. Some models can be controlled via WiFi, and have angled/tilted drums to facilitate loading.[24][25][26]

Even on some expensive washers, the outer drum of front-loading machines is often (but not always) made of plastic (it can also be made out of metal, but this is expensive). This makes changing the main bearings difficult, as the plastic drum usually cannot be separated into two halves to enable the inner drum to be removed to gain access to the bearing.

Many residential front-loading washing machines typically have a 25 kg (55 lb) concrete block to dampen vibration.[27] Alternatives include a plastic counterweight that can be filled with water after delivery,[27] reducing or controlling motor speeds, using hydraulic suspensions instead of spring suspensions, and having freely moving steel balls or liquid contained inside a ring mounted on both the top and bottom of the drum to counter the weight of the clothes and reduce vibration.[28][29]

Most newer front-load machines now use a brushless DC (BLDC) motor directly connected to the basket (direct drive), where the stator assembly is attached to the rear of the outer plastic drum assembly, whilst the co-axial rotor is mounted on the shaft of the inner drum.[30] The direct drive motor eliminates the need for a pulley, belt, and belt tensioner.[31][32][33][34][35] It was first introduced to washing machines by Fisher and Paykel in 1991. Since then, other manufacturers have followed suit. Some washing machines with this type of motor now come with 10-year or 20-year warranties.[36][37] The motor type used is an outrunner, due to its slim design with variable speed and high torque. The rotor is connected to the inner tub through its center. It can be made of metal or plastic. Some direct drive washers use induction motors instead of BLDC motors.[38]

Additional features

[edit]

The modern washing machine market has seen several innovations and features, examples including:

- Washing machines including water jets (also known as water sprays, jet sprays[39] and water showers) and steam nozzles[40] that claim to sanitize clothes, help reduce washing times, and remove soil from the clothes.[41] Water jets get their water from the bottom of the drum, thus recirculating the water in the washer.[42][43][44]
- Others have special drums with holes that will fill with water from the bottom of the tub and redeposit the water on top of the clothes. Some drums have elements with the shape of waves, pyramids, hexagons, domes, or diamonds.[45][46][47][48]
- Some include titanium or ceramic heating elements that claim to eliminate calcium buildup in the element.[49] They can heat water up to 95 °C (203 °F).
- Some high-end models have lights built into the washer itself to light the drum,[40]
- Others have soap dispensers where the user fills a tank[50][51] with detergent and softener and the washing machine automatically doses the detergent and softener[52] and, in some cases, chooses the most appropriate wash cycle.[53] In some models, the tanks come pre-filled and are installed and replaced with new tanks, also pre-filled or refilled by the user, in a dedicated compartment on the bottom of the machine.[54]
- Some have support for single-use capsules containing enough laundry additives for one load. The capsules are installed in the detergent compartment.[55][56]
- Many dilute the detergent before it comes in contact with the clothes,[57][58][59][60][61] some by means of mixing the soap and water with air to make foam,[62] which is then introduced into the drum and improves cleaning performance.[63][64][65][66] Alternatively micro bubbles may be used instead.[67][68]

- Some have pulsators that are mounted on a plate on the bottom of the drum instead of an agitator.[69][70][71] The plate spins, and the pulsators generate waves that help shake the soil out of the clothes. Many also include mechanisms to prevent or remove undissolved detergent residue on the detergent dispenser.[72][73][74]
- It is possible to incorporate a blower and a nozzle to smooth wrinkles in clothes without removing them from the washer.[75][76]
- Some manufacturers like LG Electronics and Samsung Electronics have introduced functions on their washers that allow users to troubleshoot common problems with their washers without having to contact technical support. LG's approach involves a phone receiving signals through sound tones, while Samsung's approach involves having the user take a photo of the washer's time display with a phone. In both methods, the problem and steps to resolve it are displayed on the phone itself.[77][78] Some models are also NFC enabled.[79] Some implementations are patented under US Patent US20050268669A1 and US Patent US20050097927A1.

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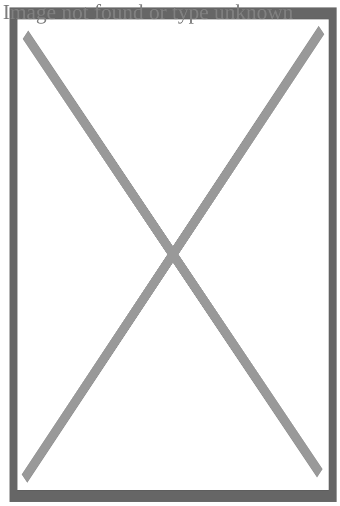


A see-through Bosch machine at the IFA 2010 in Berlin shows its internal components.

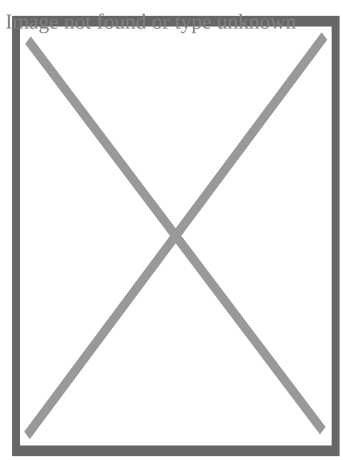
In the early 1990s, upmarket machines incorporated microcontrollers for the timing process. These proved reliable and cost-effective, so many cheaper machines now also incorporate microcontrollers rather than electromechanical timers. Since the 2010s, some machines have had touchscreen displays, full-color or color displays, or touch-sensitive control panels.[80][81]

In 1994, Staber Industries released the System 2000 washing machine, which is the only top-loading, horizontal-axis washer to be manufactured in the United States. The hexagonal tub spins like a front-loading machine, using only about one-third as much water as conventional top-loaders. This factor has led to an Energy Star rating for its high efficiency. This type of horizontal-axis washer and dryer (with a circular drum) is often used in Europe, where space is limited, as they can be as thin as 41 cm (16 in) in width.[82]

In 1998, New Zealand-based company Fisher & Paykel introduced its SmartDrive washing machine line in the US. This washing machine uses a computer-controlled system to determine factors such as load size and adjusts the wash cycle to match. It also used a mixed system of washing, first with the "Eco-Active" wash, using a low level of recirculated water being sprayed on the load followed by a more traditional style wash. The SmartDrive also included a direct drive brushless DC electric motor, which simplified the bowl and agitator drive by eliminating the gearbox system.

In 2000, the British inventor James Dyson launched the CR01 ContraRotator, a type of washing machine with two cylinders rotating in opposite directions. It was claimed that this design reduced the wash time and produced cleaner washing than a single-cylinder machine. In 2004 the launch of the CR02, was the first washing machine to gain the British Allergy Foundation Seal of Approval. However, neither of the ContraRotator machines is now in production as they were expensive to manufacture. They were discontinued in 2005.[83][84] It is patented under U.S. Patent US7750531B2, U.S. Patent US6311527, U.S. Patent US20010023513, U.S. Patent US6311527B1, U.S. Patent USD450164.[85]

In 2001, Whirlpool Corporation introduced the Calypso, the first vertical-axis high-efficiency washing machine to be top-loading. A washplate in the bottom of the tub nutated (a special wobbling motion) to bounce, shake, and toss the laundry. Simultaneously, water containing detergent was sprayed onto the laundry. The machine proved to be good at cleaning but gained a bad reputation due to frequent breakdowns and destruction of laundry. The washer was recalled with a class-action lawsuit[86] and pulled off the market.



A Beko washing machine; modern household washing machines start at 1 kg (2 lb) capacity, designed for smaller households, and span to 24 kg (53 lb) load capacity.

In 2003, Maytag introduced their top-loading Neptune TL FAV6800A and TL FAV9800A washers. Instead of an agitator, the machine had two washplates, perpendicular to each other and at a 45-degree angle from the bottom of the tub. The machine would fill with only a small amount of water and the two wash plates would spin, tumbling the load within it, mimicking the action of a front-loading washer in a vertical-axis design.[87][88][89][90][91][92]

In 2006, Sanyo introduced the "world-first" (as of February 2, 2006, with regards to home use drum-type washer/dryer) drum-type washing machine with "Air Wash" function (i.e.: using ozone as a disinfectant). It also reused and disinfected rinse water.[93] This washing machine uses only 50 L (11.0 imp gal; 13.2 US gal) of water in the recycle mode.

Approximately in 2012, eco-indicators were introduced, capable of predicting the energy demand based on the customer settings in terms of program and temperature.[94]

Features available in most modern consumer washing machines:

- Delayed execution: a timer to delay the start of the laundry cycle
- Predefined programs for different laundry types
- Rotation speed settings
- Variable temperatures, including cold wash

Additionally, some modern machines feature:

- Child lock[95]
- Steam
- Time remaining indication
- Extra water/rinse.
- UV disinfection.[96]

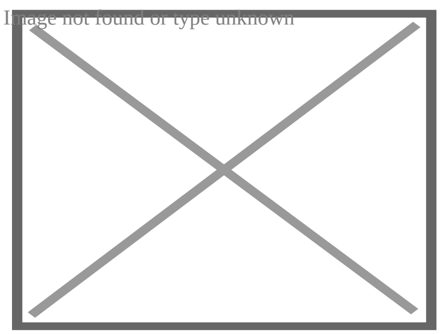
Around 2015 and 2017, some manufacturers[97][98][99] (namely Samsung and LG Electronics) offered washers and dryers that either have a top-loading washer and dryer built on top of a front-loading washer and dryer respectively (in Samsung washers and dryers) or offer users an optional top-loading washer that can be installed under a washer or dryer (for LG washers and dryers) Both manufacturers have also introduced front-loading washers allowing users to add items after a wash cycle has started,[100][101] and Samsung has also introduced top-loading washers with a built-in sink[102] and a detergent dispenser that claims to leave no residue on the dispenser itself. In IFA 2017,[103] Samsung released the QuickDrive, a front-loading washer similar to the Dyson ContraRotator but instead of two counter-rotating drums, the QuickDrive has a single drum with a counter-rotating impeller mounted on the back of the drum. Samsung claims this technique reduces cycle times by half and energy consumption by 20%. The US has introduced standards for washing machines that improve their energy efficiency and reduce their water consumption.[104][105]

Types

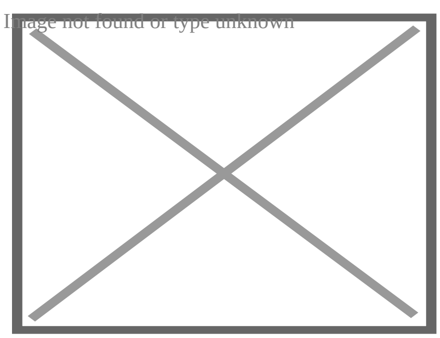
[edit]

Top-loading

[edit]



General Electric Filter-Flo top-loading, vertical-axis machines installed in a laundromat. The pans on the inside of the lid are placed atop the agitator, and wash water is pumped through the perforated pans to collect lint. (California)



In a top-loading washer, water circulates primarily along the poloidal axis during the wash cycle, as indicated by the red arrow in this illustration of a torus.

The top-loading, vertical-axis washer has been the dominant design in the United States and Canada. This design places the clothes in a vertically mounted perforated basket that is contained within a water-retaining tub, with a finned water-pumping agitator in the center of the bottom of the basket. Clothes are loaded through the top of the machine, which is usually but not always covered with a hinged door. The drum of a top loading washing machine can include a lint trap.[106]

Agitation

[edit]

During the wash cycle, the outer tub is filled with water sufficient to fully immerse and suspend the clothing freely in the basket. The movement of the agitator pushes water outward between the paddles towards the edge of the tub. The water then moves outward, up the sides of the basket, towards the center, and then down towards the agitator to repeat the process, in a circulation pattern similar to the shape of a torus. The agitator direction is periodically reversed because continuous motion in one direction would just lead to the water spinning around the basket with the agitator rather than the water being pumped in the torus-shaped motion. Some washers supplement the water-pumping action of the agitator with a large rotating screw on the shaft above the agitator, to help move water downwards in the center of the basket. A washing machine can have an impeller, also called a wash plate, instead of an agitator, which serves the same purpose but does not have a vertical cylinder extending from its base.

Since the agitator and the drum are separate and distinct in a top-loading washing machine, the mechanism of a top-loader is inherently more complicated than a front-loading machine. Manufacturers have devised several ways to control the motion of the agitator during the wash and rinse separately from the high-speed rotation of the drum required for the spin cycle. While a top-loading washing machine could use a universal motor or DC brushless motor, it is conventional for top-loading washing machines to use more expensive, heavy, and potentially more electrically efficient and reliable induction motors.

An alternative to this oscillating agitator design is the impeller-type washtub pioneered by Hoover on its long-running *Hoovermatic* series of top-loading machines. Here, an impeller (trademarked by Hoover as a "Pulsator") mounted on the side of the tub spins in a constant direction and creates a fast-moving current of water in the tub which drags the clothes through the water along a toroidal path. This design was used in the Hoover 0307 washer. The impeller design has the advantage of mechanical simplicity – a single-speed motor with belt drive is all that is required to drive the Pulsator with no need for gearboxes or complex electrical controls, but has the disadvantage of lower load capacity in relation to tub size. Hoovermatic machines were made mostly in twin-tub format for the European market (where they competed with Hotpoint's *Supermatic* line which used the oscillating agitator design) until the early 1990s. Some industrial garment testing machines still use the Hoover wash action. Another alternative involves 'pulsating' the agitator, in other words having an agitator with a reciprocating motion along its vertical axis.[107] Some washing machines have agitators that move in an orbiting motion[108][109][110] or agitators that nutate at the bottom.[111][112][113][114][115] Special top loading washing machines designed for washing sneakers can incorporate bristles in their agitators.[116] Alternatively the inner tub itself can nutate inside the outer tub.[117][118]

The many different ways manufacturers have solved the same problem over the years is a good example of many different ways to solve the same engineering problem with different goals, different manufacturing capabilities and expertise, and different patent encumbrances.

Reversible motor

[edit]

In many current top-loading washers, if the motor spins in one direction, the gearbox drives the agitator; if the motor spins the other way, the gearbox locks the agitator and spins the basket and agitator together. Similarly, if the pump motor rotates one way it recirculates the sudsy water; in the other direction it pumps water from the machine during the spin cycle. Mechanically, this system is very simple.[38]

Mode-changing transmission

[edit]

In some top-loaders, the motor runs only in one direction. During agitation, the transmission converts the rotation into the alternating motion driving the agitator. During the spin cycle, the timer turns on a solenoid which engages a clutch locking the motor's rotation to the wash basket, providing a spin cycle. General Electric's very popular line of Filter-Flo (seen to the right) used a variant of this design where the motor reversed only to pump water out of the machine. The same clutch which allows the heavy tub full of wet clothes to "slip" as it comes up to the motor's speed, is also allowed to "slip" during agitation to engage a Gentle Cycle for delicate clothes.

Whirlpool (Kenmore) created a popular design demonstrating the complex mechanisms which could be used to produce different motions from a single motor with the so-called "wig wag" mechanism, which was used for decades until modern controls rendered it obsolete. In the Whirlpool mechanism, a protruding moving piece oscillates in time with the agitation motion. Two solenoids are mounted to this protruding moving piece, with wires attaching them to the timer. During the cycle, the motor operates continuously, and the solenoids on the "wig wag" engage in agitation or spin. Despite the wires controlling the solenoids being subject to abrasion and broken connections due to their constant motion and the solenoids operating in a damp environment where corrosion could damage them, these machines were surprisingly reliable.

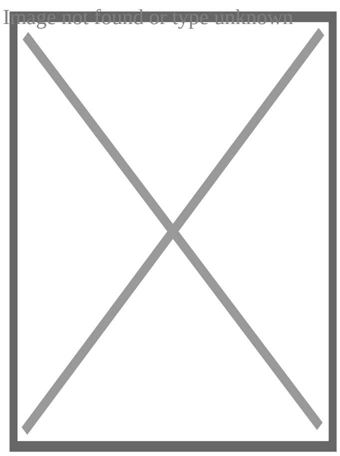
Reversible motor with mode-changing transmission

[edit]

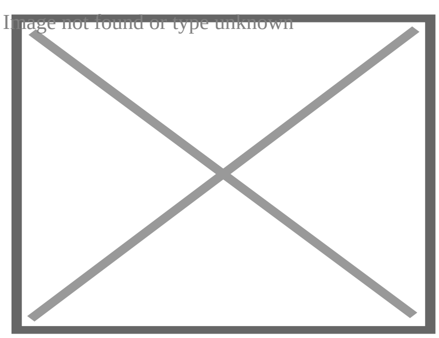
Some top-loaders, especially compact apartment-sized washers, use a hybrid mechanism. The motor reverses direction every few seconds, often with a pause between direction changes, to perform the agitation. The spin cycle is accomplished by engaging a clutch in the transmission. A separate motorized pump is generally used to drain this style of machine. These machines could easily be implemented with universal motors or more modern DC brushless motors, but older ones tend to use a capacitor-start induction motor with a pause between reversals of agitation.[119]

Front-loading

[edit]



Arctic BE1200A+ is a front-loading budget model sold in 2008 with 6-kilogram (13 lb) load, LCD indicator, operating up to 1200 RPM.



Modern drum of front-loading washing machine (Bosch Maxx WFO 2440)

The front-loading or horizontal-axis clothes washer is the dominant design in Europe and in most parts of the world. In the United States and Canada, most "high-end" washing machines are of this type. In addition, most commercial and industrial clothes washers around the world are of the horizontal-axis design.

This layout mounts the inner drum and outer drum horizontally, and loading is through a door at the front of the machine. The door often but not always contains a transparent window. Agitation is supplied by the back-and-forth rotation of the cylinder and by gravity.

The clothes are lifted by paddles on the inside wall of the drum and then dropped. This motion flexes the weave of the fabric and forces water and detergent solution through the clothes load. Because the wash action does not require the clothing to be freely suspended in water, only enough water is needed to moisten the fabric. Because less water is required, front-loaders typically use less soap, and the repeated dropping and folding action of the tumbling can easily produce large amounts of foam or suds.

Front-loaders control water usage through the surface tension of water, and the capillary wicking action this creates in the fabric weave. A front-loader washer always fills to the same low water level, but a large pile of dry clothing standing in water will soak up the moisture, causing the water level to drop. The washer then refills to maintain the original water level. Because it takes time for this water absorption to occur with a motionless pile of fabric, nearly all front-loaders begin the washing process by slowly tumbling the clothing under the stream of water entering and filling the drum, to rapidly saturate the clothes with water.

Compared to top-loading washers, clothing can be packed more tightly in a front loader, up to the full drum volume if using a cotton wash cycle. This is because wet cloth usually fits into a smaller space than dry cloth, and front-loaders can self-regulate the water needed to achieve correct washing and rinsing. However, extreme overloading of front-loading washers pushes fabrics towards the small gap between the loading door and the front of the wash basket, potentially resulting in fabrics lost between the basket and outer tub, and in severe cases, tearing of clothing and jamming the motion of the basket.

Mechanical aspects

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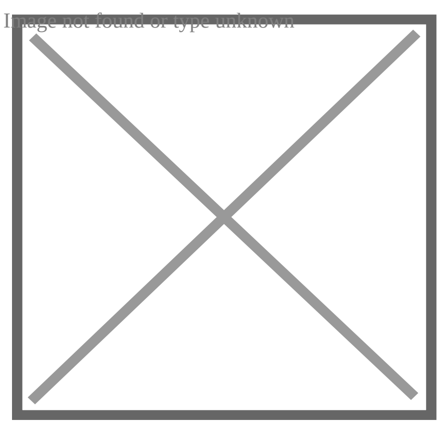
Front-loading washers are mechanically simple compared to top-loaders, with the main motor (a universal motor or variable-frequency drive motor) normally being connected to the drum via a grooved pulley belt and large pulley wheel without the need for a gearbox, clutch or crank. The action of a front-loading washing machine is better suited to a motor capable of reversing direction with every reversal of the wash drum; a universal motor is noisier, less efficient, and does not last as long, but is better suited to the task of reversing direction every few seconds. Some models, such as those by LG, use a motor directly connected to the drum, eliminating the need for a belt and pulley.

However, front-load washers suffer from their own technical challenges due to the horizontal disposition of the drum. A top-loading washer keeps water inside the tub merely through the force of gravity pulling down on the water, while a front-loader must tightly seal the door with a gasket to prevent water dripping onto the floor during the wash cycle. This access door is locked shut with an interlocking device during the entire wash cycle, since opening the door with the machine in use could result in water gushing onto the floor. If this interlock is broken for any reason, such a machine stops operation, even if this failure happens mid-cycle. In most machines, the interlock is usually doubly redundant to prevent either opening with the drum full of water or being opened during the spin cycle. For front-loaders without viewing windows on the door, it is possible to accidentally pinch the fabric between the door and the drum, resulting in tearing and damage to the pinched clothing during tumbling and spinning.

Nearly all front-loader washers for the consumer market also use a folded flexible bellows assembly around the door opening to keep clothing contained inside the drum during the tumbling wash cycle. If this bellows assembly were not used, small articles of clothing such as socks could slip out of the wash drum near the door and fall down the narrow slot between the outer and inner drums, plugging the drain and possibly jamming rotation of the inner drum. Retrieving lost items from between the outer drum and inner drum can require complete disassembly of the front of the washer and pulling out the entire inner wash drum. Commercial and industrial front-loaders used by businesses (described below) usually do not use the bellows, but instead require all small objects to be placed in a mesh bag to prevent loss near the drum opening.

Variant and hybrid designs

[edit]



European top-loader with horizontal-axis rotating drum (2008)

There are many variations of the two general designs. Top-loading machines in Asia use impellers instead of agitators. Impellers are similar to agitators except that they do not have the center post extending up in the middle of the washtub basket.

Horizontal-axis top-loader

[edit]

Some machines which load from the top are otherwise much more similar to front-loading horizontal-axis drum machines. They have a drum rotating around a horizontal axis, as a front-loader, but there is no front door; instead, there is a liftable lid that provides access to the drum, which has a hatch that can be latched shut. Clothes are loaded, the hatch and lid are closed, and the machine operates and spins just like a front loader. These machines are narrower but usually taller than front-loaders, usually have a lower capacity, and are intended for use where only a narrow space is available, as is sometimes the case in Europe. They have incidental advantages: they can be loaded while standing (but force the user to bend down instead of crouching down or sitting to unload); they do not require a perishable rubber bellows seal; and instead of the drum having a single bearing on one side, it has a pair of symmetrical bearings, one on each side, avoiding asymmetrical bearing loading and potentially increasing life.

Combo washer dryer

[edit]

There are also combo washer dryer machines that combine washing cycles and a full drying cycle in the same drum, eliminating the need to transfer wet clothes from a washer to a dryer machine. In principle, these machines are convenient for overnight cleaning (the combined cycle is considerably longer), but the effective capacity for cleaning larger batches of laundry is drastically reduced. The drying process tends to use much more energy than using two separate devices, because a combo washer dryer not only must dry the clothing but also needs to dry out the wash chamber itself.

These machines are used more where space is at a premium, such as areas of Europe and Japan because they can be fit into small spaces, perform both washing and drying, and many can be operated without dedicated utility connections. In these machines, the washer and dryer functions often have different capacities, with the dryer usually having the lowest capacity.

These combo machines should not be confused with a dryer on top of a washer installation, or with a laundry center, which is a one-piece appliance offering a compromise between a washer-dryer combo and a full washer to the side of the dryer installation or a dryer on top of a washer installation. Laundry centers usually have the dryer on top of the washer, with the controls for both machines being on a single control panel. Often, the controls are simpler than the controls on a washer-dryer combo or a dedicated washer and dryer. Some implementations are patented under US Patent US6343492B1 and US Patent US 6363756B1.

Comparison

[edit]

True front-loading machines, top-loading machines with horizontal-axis drums, and true top-loading vertical-axis machines can be compared on several aspects:

- Efficient cleaning: Front loaders usually use less energy, water, and detergent compared to the best top-loaders.[120] High-efficiency washers use 20% to 60% of the detergent, water, and energy of "standard" commonly-used top-loader washers. They usually take somewhat longer (20–110 minutes) to wash a load, but are often computer controlled with additional sensors, to adapt the wash cycle to the needs of each load.
- Water usage: Front-loaders usually use less water than top-loading residential clothes washers. Estimates are that front-loaders use from one-third [121] to one half [122] as much water as top-loaders.
- Spin-dry effectiveness: Front-loaders (and European horizontal-axis top-loaders and some front-loaders) offer much higher maximum spin speeds of up to 2000 RPM, although home machines tend to be in the 1000 to 1400 RPM range, while top-loaders (with agitators) do not exceed 1140 RPM. High-efficiency top-loaders with a wash plate (instead of an agitator) can spin up to 1100 RPM, as their center of gravity is lower. Higher spin speeds, along with the diameter of the drum, determine the g-force, and a higher g-force removes more residual water, making clothes dry faster. This also reduces energy consumption if clothes are dried in a clothes dryer.[123]
- Cycle length: Top-loaders have tended to have shorter cycle times, in part because their design has traditionally emphasized simplicity and speed of operation more than resource conservation. It is observed that top-loaders wash the clothes in half the time as compared to a front-load washing machine.
- Wear and abrasion: Top-loaders require an agitator or impeller mechanism to force enough water through clothes to clean them effectively, which greatly increases mechanical wear and tear on fabrics. Front-loaders use paddles in the drum to repeatedly pick up and drop clothes into the water for cleaning; this gentler action causes less wear and tear. The rate of clothes wear can be roughly gauged by the amount of accumulation in a clothes dryer lint filter, since the lint largely consists of stray fibers detached from textiles during washing and drying.
- Difficult items: Top-loaders may have trouble cleaning large items, such as sleeping bags or pillows, which tend to float on top of the wash water rather than circulate within it. In addition, vigorous top-loader agitator motions may damage delicate fabrics. Whereas in a front-load washing machine, one can easily wash pillows, shoes, soft toys, and other difficult-to-wash items.
- Noise: Front-loaders tend to operate more quietly than top-loaders because the door seal helps contain noise, and because there is less of a tendency towards

imbalance. Top loaders usually need a mechanical transmission (due to agitators, see above), which can generate more noise than the rubber belt or direct drive found in most front-loaders.

- Compactness: True front-loading machines may be installed underneath counter-height work surfaces. A front-loading washing machine, in a fully fitted kitchen, may even be disguised as a kitchen cabinet. These models can also be convenient in homes with limited floor area, since the clothes dryer may be installed directly above the washer ("stacked" configuration).
- Water leakage: Top-loading machines are less prone to leakage because simple gravity reliably keeps water from spilling out the loading door on top. True front-loading machines require a flexible seal or gasket on the front door, and the front door must be locked during operation to prevent opening, lest large amounts of water spill out. This seal may leak and require replacement. However, many current front-loaders use so little water that they can be stopped mid-cycle for the addition or removal of laundry, while keeping the water level in the horizontal tub below the door level. Best practice installations of either type of machine will include a floor drain or an overflow catch tray with a drain connection, since neither design is immune to leakage or a solenoid valve getting stuck in the open position.
- Maintenance and reliability: Top-loading washers are more tolerant of maintenance neglect, and may not need a regular "freshening" cycle to clean door seals and bellows. During the spin cycle, a top-loading tub is free to move about inside the cabinet of the machine, using only a lip around the top of the inner basket and outer tub to keep the spinning water and clothing from spraying out over the edge. Therefore, the potentially problematic door-sealing and door-locking mechanisms used by true front-loaders are not needed. On the other hand, top-loaders use mechanical gearboxes that are more vulnerable to wear than simpler front-load motor drives.
- Accessibility and ergonomics: Front-loaders are more convenient for shorter people and those with paraplegia, as the controls are front-mounted and the horizontal drum eliminates the need for standing or climbing. Risers, also referred to as pedestals, often with storage drawers underneath, can be used to raise the door of a true front-loader closer to the user's level. However, if stacked, the dryer controls, if at the top of the dryer, may be too tall for shorter people to conveniently access.
- Initial cost: In countries where top-loaders are popular, front-loaders tend to be more expensive to buy than top-loaders, though their lower operating costs can lead to lower total cost of ownership, especially if energy, detergent, or water are expensive. On the other hand, in countries with a large front-loader user base, top-loaders are usually seen as alternatives and more expensive than basic off-brand front-loaders, although without many differences in total cost of ownership apart from design-originated ones. In addition, manufacturers have tended to include more advanced features such as internal water heating, automatic dirt sensors, and high-speed emptying on front loaders, although some of these features could be implemented on top loaders.

Wash cycles

[edit]

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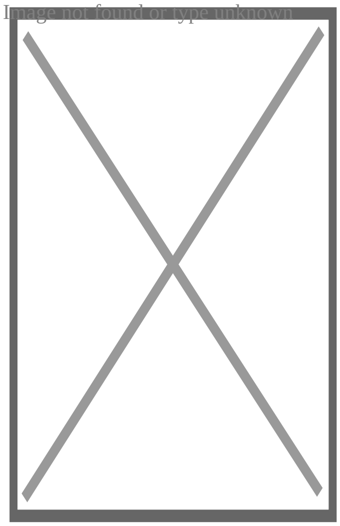

German laundry centrifuge to extract water from laundry; the advent of automatic washing machines with spin cycles made such specialized appliances largely obsolete by the 1970s.

The earliest washing machines simply carried out a washing action when loaded with clothes and soap, filled with hot water, and started. Over time machines became more and more automated, first with complex electromechanical controllers, then fully electronic controllers; users put clothes into the machine, select a suitable program via a switch, start the machine, and come back to remove clean and slightly damp clothes at the end of the cycle. The controller starts and stops many different processes including pumps and valves to fill and empty the drum with water, heating, and rotating at different speeds, with different combinations of settings for different fabrics.

Longer wash cycles can allow greater water and energy efficiency (with less water to heat up). For a 3.5 kg (7.7 lb) load, from 2011 to 2021, the average Australian washing machine cycle (including rinsing and spinning) has lengthened from 99 to 144 minutes for front-loaders, and 55 to 59 minutes for top-loaders.[124]

Washing

[edit]

Many front-loading machines have internal electrical heating elements to heat the wash water, to near boiling if desired. The rate of the chemical cleaning action of the detergent and other laundry chemicals increases greatly with temperature, by the Arrhenius equation. Washing machines with internal heaters can use special detergents formulated to release different chemical ingredients at different temperatures, allowing different types of stains and soils to be cleaned from the clothes as the wash water is heated by the electrical heater.

However, higher-temperature washing uses more energy, and many fabrics and elastics are damaged at higher temperatures. Temperatures exceeding 40 °C (104 °F) have the undesirable effect of deactivating the enzymes when using biological detergent.

Many machines are cold-fill, connected to cold water only, which they internally heat to operating temperature. Where water can be heated more cheaply or with less carbon dioxide emission than by electricity, a cold-fill operation is inefficient.

Front-loaders need to use low-sudsing detergents because the tumbling action of the drum entrains air into the clothes load, which can cause excessive foamy suds and overflows. However, due to the efficient use of water and detergent, the suds issue with front-loaders can be controlled by simply using less detergent, without lessening the cleaning action.

Rinsing

[edit]

Washing machines perform several rinses after the main wash to remove most of the detergent. Modern washing machines use less hot water due to environmental concerns; however, this has led to the problem of poor rinsing on many washing machines on the market,[125] which can be a problem to people who are sensitive to detergents. The Allergy UK website suggests re-running the rinse cycle, or rerunning the entire wash cycle without detergent.[126]

In response to complaints, many washing machines allow the user to select additional rinse cycles, at the expense of higher water usage and longer cycle time. Bosch, for example, in its allergy wash program, incorporates an additional three-minute rinse cycle with water of at least 60 °C (140 °F) to rinse off detergent residues and any allergens.[127]

Spin

[edit]

Front-loading machines spin in multiple stages of their cycle: after main wash, after individual rinses, and the final high-speed spin. Some of those spins may be absent depending on the particular cycle.

Higher spin speeds, along with larger tub diameters, remove more water, leading to faster drying. On the other hand, the need for ironing can be reduced by not using the spin cycle in the washing machine.

If a heated clothes dryer is used after the wash and spin, energy use is reduced if more water has been removed from clothes. However, faster spinning can crease clothes more. Also, mechanical wear on bearings increases rapidly with rotational speed, reducing life. Early machines would spin at 300 rpm and, because of lack of any mechanical suspension, would often shake and vibrate.

In 1976, most front-loading washing machines spun at around 700 RPM, or less.[*citation needed*] Today, most machines spin at 1000–1600 RPM. Most machines have variable speeds, ranging 300–2000 RPM depending on the machine.

Separate spin-driers, without washing functionality, are available for specialized applications. For example, a small high-speed centrifuge machine may be provided in locker rooms of communal swimming pools to allow wet swimsuits to be substantially dried to a slightly damp condition after daily use.

Washing machines often incorporate balance rings filled with a liquid such as a calcium chloride salt water solution,[128] that are designed to balance the inner drum of the washer during spin cycles.[129][130] The balance ring may be filled with oil and contain balls on races, somewhat similarly to a ball bearing, to achieve the same effect.[131][132] The Bendix Economat used a flexible rubber inner tub that would squeeze the clothes towards the agitator located in the center of the inner tub in order to remove water from the clothes, instead of spinning the inner tub. This was performed by exerting a vacuum on the inner tub.[133][134]

Maintenance wash

[edit]

Many home washing machines use a plastic, rather than metal, outer shell to contain the wash water; residue can build up on the plastic tub over time. Some manufacturers advise users to perform a regular maintenance or "freshening" wash to clean the inside of the washing machine of any mold, bacteria, encrusted detergent, and unspecified dirt more effectively than with a normal wash.[*citation needed*]

A maintenance wash is performed without any laundry, on the hottest wash program,[135] adding substances such as white vinegar, 100 grams of citric acid, a detergent with bleaching properties, or a proprietary washing machine cleaner. The first injection of water goes into the sump[136] so the machine can be allowed to fill for about 30 seconds before adding cleaning substances.

Installation and flood prevention

[edit]

Flexible rubber hoses are typically used to connect from a building water supply to a washing machine. These hoses are often exposed to full water pressure on a continuing basis and can deteriorate over time, developing bulges or weak spots that eventually cause leaks or catastrophic bursting and flooding. Since the hoses are often hidden from view, they may be difficult to inspect and easily forgotten until a problem occurs. If a hose burst occurs when nobody is present to notice the problem, a huge volume of water can be delivered over a short time, causing extensive interior flooding damage or even structural damage. It has been estimated that a burst supply hose can deliver two tons of water in an hour.[137]

To reduce these risks, it is a common recommendation to use flexible hoses which have been jacketed with a braided stainless steel mesh. This jacketing cannot prevent leaks from developing, but it can slow the development of large bulges or "aneurysms" which can burst suddenly without warning. However, even braided metal jackets often cannot withstand the enormous pressures generated by water freezing within an enclosed volume.

An additional precaution is to install a washing machine inside a shallow metal or plastic pan, which can collect minor leakage and divert the water to a nearby drain, or to the outside of a building. Drain pans can also divert water released by other problems, such as a jammed solenoid valve in a washing machine. A serious limitation of drain pans is that they typically cannot handle the large volumes of pressurized water released by a burst supply hose, so a drain pan is no substitute for hose burst precautions. In the absence of a drain, a pan may still be useful to confine leakage temporarily, while a local or remote water alarm is triggered.

In addition or instead of an alarm, a water detector may signal the main water shutoff valve to the building to be automatically closed to prevent flooding.[138]

A very effective precaution is to install a shutoff or isolation valve which stops any water from being supplied, except when a washing machine is actually operating. The simplest method is to manually open and close the hot and cold water shutoff valves (traditionally globe valves) behind the washing machine, each time it is used. This method relies on the washing machine user conscientiously operating the two valves each time laundry is done, in spite of the awkward location of the valves and the tedious process of turning the handles through multiple rotations.

An improvement over the traditional setup is to install a specialized laundry shutoff valve.[139] Typically, it consists of two ball valves connected to a single handle, so they can be operated by a horizontal or vertical lever moved by 90 degrees. This makes the operation of the valves a quick procedure, but the washing machine user must still remember to turn off the water, even though the failure to do this produces no immediately obvious problems.

To close this risk exposure, some shutoff valves have a spring-energized mechanical timer which is started when the user pushes a lever to open the valves. After a preset time of several hours elapses, the spring-powered mechanism automatically closes the valve without further user intervention.[137] A variant of this setup requires the user to press a button to open the valves for an electrically-timed interval.

Other automatic valve operating mechanisms electronically detect when a washing machine draws electrical power as it starts, and then open the water supply valves. Typically, the power plug for the washing machine is connected to a special detector receptacle or cable, to allowing monitoring of the power draw.[139]

Although pressurized water supply leaks can cause the most damage in the least amount of time, water drainage can also cause problems if not handled properly. Washing machine drainage hoses should be secured properly to prevent accidental dislodgement, and drains should be inspected and cleared periodically to prevent buildup of laundry lint, mold, and other deposits.[140]

Efficiency and standards

[edit]

Capacity and cost are both considerations when purchasing a washing machine. All else being equal, a machine of higher capacity will cost more to buy, but will be more convenient if large amounts of laundry must be cleaned. Fewer runs of a machine of larger capacity may have lower running costs and better energy and water efficiency than frequent use of a smaller machine, particularly for large families. However, running a large machine with small loads is typically inefficient and wasteful, unless the machine has been designed to handle such situations.

For many years energy and water efficiency were not regulated, and little attention was paid to them. From the last part of the 20th century, increasing attention was paid to efficiency, with regulations enforcing some standards. Efficiency became a selling point, both to save on running costs and to reduce carbon dioxide emissions associated with energy generation, and waste of water.

As energy and water efficiency became regulated, they became a selling point for buyers; however, the effectiveness of rinsing was not specified, and it did not directly attract the attention of buyers. Therefore, manufacturers tended to reduce the degree of rinsing after washing, saving water and electrical energy. This had the side-effect of leaving more detergent residue in clothes, which can affect people with allergies or sensitivity.[125] In response to complaints, some manufacturers have now designed their machines with a user-selectable option for additional rinsing.

Europe

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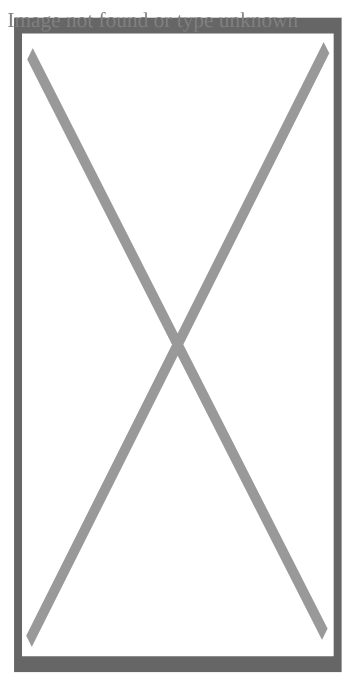


The EU requires that washing machines carry an efficiency label.

Washing machines display an EU Energy Label with grades for energy efficiency, washing performance, and spin efficiency. Grades for energy efficiency run from A+++ to D (best to worst), providing a simple method for judging running costs. Washing performance and spin efficiency are graded in the range A to G. However, all machines for sale must have washing performance A, so that manufacturers cannot compromise washing performance in order to improve the energy efficiency. This labeling has had the desired effect of driving customers toward more efficient washing machines and away from less efficient ones.

According to regulations, each washing machine is equipped with a wastewater filter. This ensures that no hazardous chemical substances are disposed of improperly through the sewage system; on the other hand, it also ensures that if there is backflow in the plumbing system, sewage cannot enter the washing machine.[9]

United States

[edit]

Top-loading and front-loading clothes washers are covered by a single national standard regulating energy consumption. The old federal standards applicable before January 2011 did not restrict water consumption; there was no limit on how much unheated rinse water could be used.[141] Energy consumption for clothes washers is quantified using the energy factor.

After new mandatory federal standards were introduced, many US washers were manufactured to be more energy- and water-efficient than required by the federal standard, or even than required by the more-stringent Energy Star standard.[142] Manufacturers were further motivated to exceed mandatory standards by a program of direct-to-manufacturer tax credits.[143]

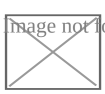
In North America, the Energy Star program compares and lists energy-efficient clothes washers. Certified Energy Star units can be compared by their Modified Energy Factor (MEF) and Water Factor (WF) coefficients.

The MEF figure of merit states how many cubic feet (about 28.3 liters) of clothes are washed per kWh (kilowatt hour). The coefficient is influenced by factors including the configuration of the washer (top-loading, front-loading), its spin speed, and the temperatures and the amount of water used in the rinse and wash cycles.

Energy Star residential clothes washers must have an MEF of at least 2.0 (the higher the better); the best machines may reach 3.5. Energy Star washers must also have a WF of less than 6.0 (the lower the better).[144]

Commercial use

[edit]



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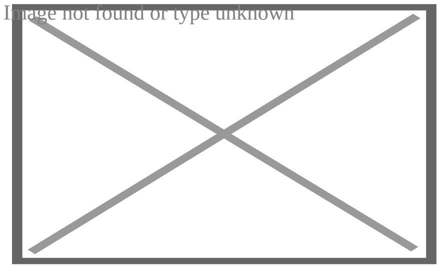
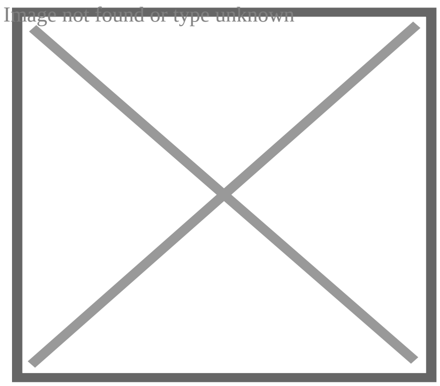


Commercial washing machines and dryers (at left) in a self-service laundry (Paris, France)



Commercial washing machines in a self-service laundromat (Toronto, Canada)

A commercial washing machine is intended for more intensive use than a consumer washing machine.[145] Durability and functionality is more important than style; most commercial washers are bulky and heavy, often with more expensive stainless steel construction to minimize corrosion in a constantly-moist environment. They are built with large easy-to-open service covers, and washers are designed not to require access from the underside for service. Commercial washers are often installed in long rows, with a wide access passageway behind all the machines to allow maintenance without moving the heavy machinery.

Laundromat machines

[edit]

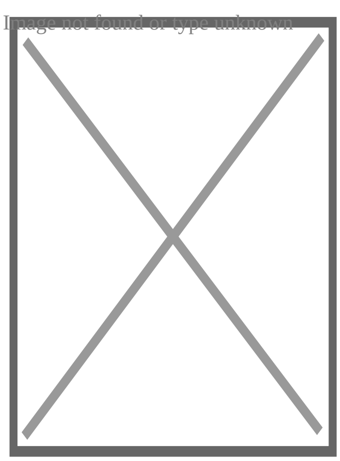
Many commercial washers are built for use by the general public, and are installed in publicly accessible laundromats or laundrettes. Originally, they were operated by coins (similar to older vending machines), but today they are activated by money accepting devices or card readers. The features of a commercial laundromat washer are usually more limited than those of a consumer washer, usually offering just two or three basic wash programs and an option to choose wash cycle temperatures. Some more-advanced models allow extra-cost options such as an additional wash or rinse cycle, at the choice of the user.

The typical front-loading commercial washing machine also differs from consumer models in its discharge of spent wash and rinse water. While the consumer models pump used washer water out, allowing the waste drainage pipe to be located above the floor level, front-loading commercial machines generally use only gravity to expel used water. A drain valve at the bottom rear of the machine opens at the appointed time during the cycle, allowing water to flow out. This requires a special drainage trough equipped with a filter and drain, and routed behind each machine. The trough is usually part of a cement platform built for the purpose of raising the machines to a convenient height, and can be seen behind washers at most laundromats.

Most laundromat machines are horizontal-axis front-loading models, because of their lower operating costs (notably, lower consumption of expensive hot water).

Industrial washers

[edit]



A 1980s Belgian 90 kg load industrial washer (horizontal axis, front load)

By contrast, commercial washers for *internal* business operations (which are often referred to as "washer/extractor" machines) may include features absent from domestic machines. Many commercial washers offer an option for automatic injection of five or more different chemical types, so that the operator does not have to deal with constantly measuring out soap products and fabric softeners for each load by hand. Instead, a precise metering system draws the detergents and wash additives directly from large liquid-chemical storage barrels, and injects them as needed into the various wash and rinse cycles. Some computer-controlled commercial washers offer the operator detailed control over the various wash and rinse cycles, allowing the operator to program custom washing cycles.

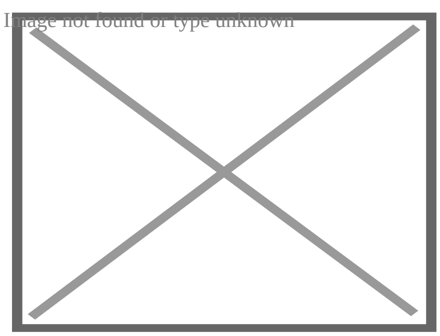
Most large-scale industrial washers are horizontal-axis machines, but they may have front-, side-, or top-load doors. Some industrial clothes washers can batch-process up to 800 pounds (360 kg) of textiles at once, and can be used for extremely machine-abusive washing tasks such as stone washing or fabric bleaching and dyeing.

An industrial washer can be mounted on heavy-duty shock absorbers and attached to a concrete floor, so that it can extract water from even the most severely out-of-balance and heavy wash loads. Noise and vibration are not as unacceptable as in a domestic machine. The machine may be mounted on hydraulic cylinders, permitting the entire washer to be lifted and tilted so that fabrics can be automatically dumped from the wash drum onto a conveyor belt once the cycle is complete.

One special type of continuous-processing washer is known as the tunnel washer. This specialized high-capacity machine does not have a drum where everything being washed undergoes distinct wash and rinse cycles. Instead, the laundry progresses slowly and continuously through a long, large-diameter horizontal-axis rotating tube in the manner of an assembly line, with different processes at different positions.[146]

Social impact

[edit]



"Woman's Friend" machine (c. 1890)

The historically laborious process of washing clothes (a task which often consumed a whole day) was at times described as "women's work". The spread of the washing machine has been seen to be a force behind the improvement of women's position in society.

Before the advent of the washing machine, laundry was done first at watercourses, and later in public wash-houses known as lavoirs. Camille Paglia and others argue that the washing machine led to a type of social isolation of women,[147] as a previously communal activity became a solitary one.

In 2009 the Italian newspaper *L'Osservatore Romano* reprinted a *Playboy* magazine article on International Women's Day arguing that the washing machine had done more for the liberation of women than the contraceptive pill and abortion rights.[148] A study from Université de Montréal, Canada presented a similar point of view, and added refrigerators.[149] The following year, Swedish statistician Hans Rosling suggested that the positive effect the washing machine had on the liberation of women makes it "the greatest invention of the industrial revolution".[150] It has been argued that washing machines are an example of labor-saving technology which does not decrease employment, because households can internalize the gains of the innovation.[151]

Historian Frances Finnegan credits the rise of domestic laundry technology in helping to undercut the economic viability of the Magdalene asylums in Ireland (later revealed to be inhumanly abusive prisons for women), by supplanting their laundry businesses and prompting the eventual closure of the institutions as a whole.[152] Irish feminist Mary Frances McDonald has described washing machines as the single most life-changing invention for women.[153]

In India, *dhobis*, a caste group specialized in washing clothes, are slowly adapting to modern technology, but even with access to washing machines, many still handwash garments as well.[154] Since most modern homes are equipped with a washing machine, many Indians have dispensed with the services of the *dhobiwallahs*.[155]

Environmental impact

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Due to the increasing cost of repairs relative to the price of a washing machine, there has been a major increase in the yearly number of defective washing machines being discarded, to the detriment of the environment. The cost of repair and the expected life of a machine may make the purchase of a new machine seem like the better option.[156]

Different washing machine models vary widely in their use of water, detergent, and energy. The energy required for heating is large compared to that used by lighting, electric motors, and electronic devices. Because of their use of hot water, washing machines are among the largest overall consumers of energy in a typical modern home.[*citation needed*][157]

Washing machines worldwide release around 62 million tonnes of carbon dioxide equivalent in a year.[*when?*] However, modern improvements have been made aiming to lower these emission numbers, and it depends on the user's choice to fully determine their environmental impact.[158][*better source needed*]

See also

[edit]

- Centrifugation
- Laundry
- Clothes dryer
- Combo washer dryer
- Detergent
- Drying cabinet

- Energetic efficiency
- Home appliance
- Ironing
- Laundry detergent
- Laundry symbols
- Laundry-folding machine
- List of home appliances
- Major appliance
- Silver Nano
- Standpipe
- Thor washing machine
- L'Increvable
- Wig wag (washing machines)

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- Preservation and also exhibition of vintage washing machines
- Washing Machines at the Canada Science and Technology Museum
- Washing Machine Museum

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Laundry

List of laundry topics

Chemicals	Bleach Fabric softener Laundry detergent ◦ pods
Washing	Combo washer dryer Dry cleaning Tunnel washer Wet cleaning Washboard Wash copper Washing machine
Drying	Clothes dryer Clothes horse Clothes line Drying cabinet Hills Hoist Mangle Dryer ball

Folding	Clothes folder
	  ◦ FoldiMate
	  ◦ Laundroid

Finishing	Box mangle Clothes hanger Ironing Laundry starch
Concepts	Colour fastness Fulling Posting Shrinkage Stain
Organizations	Chinese Hand Laundry Alliance Laundry and Dry Cleaning International Union Laundry Workers Industrial Union Project Laundry List Worshipful Company of Launderers

Culture

- Dhobi
- Housekeeping
- Industrial laundry
- Laundry symbol
- Washerwoman

Accessories

- Clothespin
- Dispensing ball
- Hamper
- Laundry ball
- Posser
- Washing paddle

Law

- *Barbier v. Connolly*
- *Kimball Laundry Co. v. United States*
- *Muller v. Oregon*
- *Pearson v. Chung*
- *Yick Wo v. Hopkins*

Places

- Baths and wash houses in Britain
- Dhobi Ghat
- Laundry room
- Lavoir
- Self-service laundry
- Tvättstuga

Home appliances

- Air conditioner
- Air fryer
- Air ioniser
- Air purifier
- Barbecue grill
- Blender
  - Immersion blender
- Bread machine
- Bug zapper
- Coffee percolator
- Clothes dryer
  - combo
- Clothes iron
- Coffeemaker
- Dehumidifier
- Dishwasher
  - drying cabinet
- Domestic robot
  - comparison
- Deep fryer
- Electric blanket
- Electric drill
- Electric kettle
- Electric knife
- Electric water boiler
- Electric heater
- Electric shaver
- Electric toothbrush
- Epilator
- Espresso machine
- Evaporative cooler
- Food processor
- Fan
  - attic
  - bladeless
  - ceiling
  - Fan heater
  - window

Types

- Freezer
- Garbage disposer
- Hair dryer
- Hair iron
- Humidifier
- Icemaker
- Ice cream maker
- Induction cooker
- Instant hot water dispenser
- Juicer
- Kitchen hood
- Kitchen stove

See also

- Appliance plug
- Appliance recycling

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Plumbing

Fundamental concepts

- Air gap (plumbing)
- Backflow
- Compatibility (chemical)
- Corrosion
- Drain (plumbing)
- Drinking water
- Fuel gas
- Friction loss
- Grade (slope)
- Greywater
- Heat trap
- Hydrostatic loop
- Leak
- Neutral axis
- Onsite sewage facility
- Pressure
- Sanitary sewer
- Sewer gas
- Sewage
- Sewerage
- Siphon
- Storm sewer
- Stormwater
- Surface tension
- Tap water
- Thermal expansion
- Thermal insulation
- Thermosiphon
- Trap (plumbing)
- Venturi effect
- Wastewater
- Water hammer
- Water supply network
- Water table
- Well

Technology

- Brazing
- British Standard Pipe (BSP)
- Cast iron pipe
- Chemical drain cleaners
- Compression fitting
- Copper tubing
- Crimp (joining)
- Drain-waste-vent system
- Ductile iron pipe
- Flare fitting
- Garden Hose Thread (GHT)
- Gasket
- Hydronics
- Leak detection
- National Pipe Thread (NPT)
- Nominal Pipe Size (NPS)
- O-ring
- Oakum
- Pipe (fluid conveyance)
- Pipe dope
- Pipe support
- Plastic pipework
- Push-to-pull compression fittings
- Putty
- Sealant
- Sewage pumping
- Soldering
- Solvent welding
- Swaging
- Thread seal tape
- Threaded pipe
- Tube bending
- Water heat recycling

Components

- Atmospheric vacuum breaker
- Automatic bleeding valve
- Automatic faucet
- Backflow prevention device
- Ball valve
- Bleed screw
- Booster pump
- Butterfly valve
- Check valve
- Chemigation valve
- Chopper pump
- Circulator pump
- Cistern
- Closet flange
- Concentric reducer
- Condensate pump
- Coupling (piping)
- Diaphragm valve
- Dielectric union
- Double check valve
- Eccentric reducer
- Expansion tank
- Faucet aerator
- Float switch
- Float valve
- Floor drain
- Flow limiter
- Flushing trough
- Flushometer
- Gate valve
- Globe valve
- Grease trap
- Grinder pump
- Hose coupling
- Manifold
- Needle valve
- Nipple (plumbing)
- Pinch valve
- Piping and plumbing fitting
- Plug (sanitation)
- Pressure regulator
- Pressure vacuum breaker
- Pressure-balanced valve
- Pump
- Radiator (heating)
- Reduced pressure zone device
- Reducer
- Relief valve
- Riser clamp
- Rooftop water tower

Plumbing fixtures

- Accessible bathtub
- Bathtub
- Bidet
- Dehumidifier
- Dishwasher
- Drinking fountain
- Electric water boiler
- Evaporative cooler
- Flush toilet
- Garbage disposal unit
- Hot water storage tank
- Humidifier
- Icemaker
- Instant hot water dispenser
- Laundry tub
- Shower
    - water recycling shower
- Sink
- Storage water heater
- Sump pump
- Tankless water heater
- Urinal
- Washing machine
- Washlet
- Water dispenser
- Water filter
- Water heater
- Water softener

Specialized tools

- Basin wrench
- Blowtorch
- Borescope
- Core drill
- Drain cleaner
- Driving cap
- Flare-nut wrench
- Pipecutter
- Pipe wrench
- Plumber's snake
- Plumber wrench
- Plunger
- Strap wrench
- Tap and die

Measurement and control

- Control valve
- Flow sensor
- Pressure sensor
- Water detector
- Water metering

Professions, trades, and services

- Hydronic balancing
- Hydrostatic testing
- Leak detection
- Mechanical, electrical, and plumbing
- Pipe marking
- Pipefitter
- Pipelayer
- Plumber

Industry organizations and standards

- International Association of Plumbing and Mechanical Officials (IAPMO)
- NSF International
- Plumbing & Drainage Institute (PDI)
- Uniform Plumbing Code (UPC)
- World Plumbing Council (WPC)

Health and safety

- Plumbing code
- Scalding
- Waterborne disease

See also

- Fire sprinkler system
- Piping
- Template:HVAC
- Template:Public health
- Template:Sewerage
- Template:Toilets
- Template:Wastewater

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About Trailer (vehicle)

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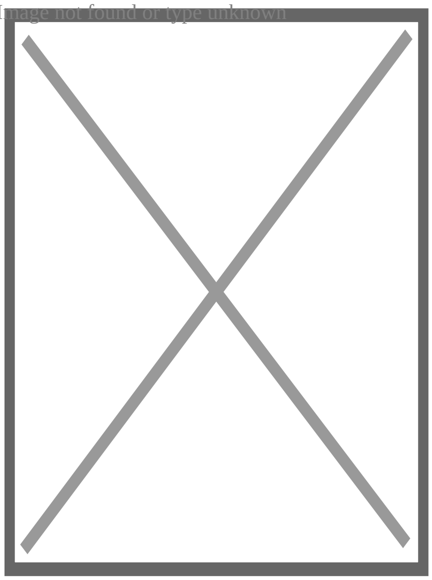
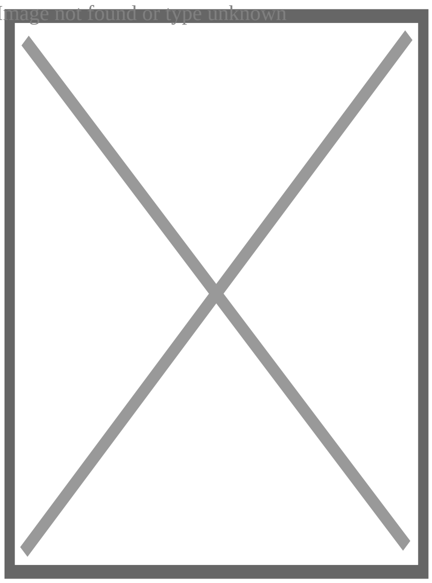
Find sources: "Trailer" vehicle – news · newspapers · books · scholar · JSTOR *(July 2017) (Learn how and when to remove this message)*



Utility trailer with a folded loading ramp



A boat on a single-axle trailer

A **trailer** is an unpowered vehicle towed by a powered vehicle. It is commonly used for the transport of goods and materials.

Sometimes recreational vehicles, travel trailers, or mobile homes with limited living facilities where people can camp or stay have been referred to as trailers. In earlier days, many such vehicles were towable trailers.

Alexander Winston is widely credited for inventing the trailer in Cleveland, Ohio.[1]

United States

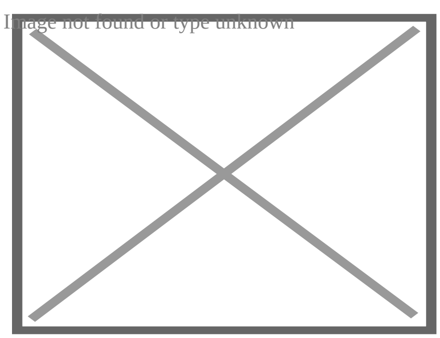
[edit]

In the United States, the term is sometimes used interchangeably with travel trailer and mobile home, varieties of trailers, and manufactured housing designed for human habitation. Their origins lay in utility trailers built in a similar fashion to horse-drawn wagons. A trailer park is an area where mobile homes are placed for habitation.

In the United States trailers ranging in size from single-axle dollies to 6-axle, 13-foot-6-inch-high (4.1 m), 53-foot-long (16.2 m) semi-trailers are commonplace. The latter, when towed as part of a tractor-trailer or "18-wheeler", carries a large percentage of the freight that travels over land in North America.

Types

[edit]



ACP Backtracking genset trailer

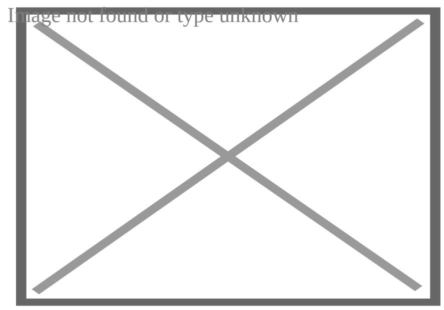
Some trailers are made for personal (or small business) use with practically any powered vehicle having an appropriate hitch, but some trailers are part of large trucks called semi-trailer trucks for transportation of cargo.

Enclosed toy trailers and motorcycle trailers can be towed by commonly accessible pickup truck or van, which generally require no special permit beyond a regular driver's license. Specialized trailers like open-air motorcycle trailers, bicycle trailers are much smaller, accessible to small automobiles, as are some simple trailers, have a drawbar and ride on a single axle. Other trailers, such as utility trailers and travel trailers or campers come in single and multiple axle varieties, to allow for varying sizes of tow vehicles.

There also exist highly specialized trailers, such as genset trailers, pusher trailers and other types that are also used to power the towing vehicle. Others are custom-built to hold entire kitchens and other specialized equipment used by carnival vendors. There are also trailers for hauling boats.

Trackless train

[edit]



Touristic road train in Nantes, France. It has three trailers.

Main article: Trackless train

[icon] This section **needs expansion**. You can help by adding to it. *(July 2021)*

Utility

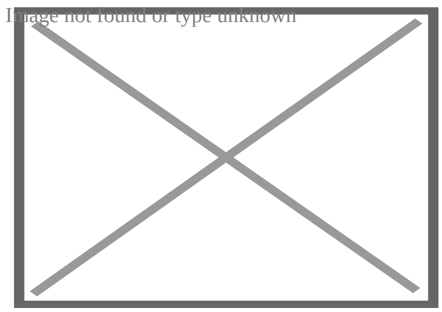
[edit]
See also: Off-road trailer

A **utility trailer** is a general purpose trailer designed to by towed by a light vehicle and to carry light, compact loads of up to a few metric tonnes. It typically has short metal sides (either rigid or folding) to constrain the load, and may have cage sides, and a rear folding gate or ramps. Utility trailers do not have a roof. Utility trailers have one axle set comprising one, two or three axles. If it does not have sides then it is usually called a flatbed or flat-deck trailer. If it has rails rather than sides, with ramps at the rear, it is usually called an open car transporter, auto-transporter, or a plant trailer, as they are designed to transport vehicles and mobile plant. If it has fully rigid sides and a roof with a rear door, creating a weatherproof compartment, this is usually called a furniture trailer, cargo trailer, box van trailer or box trailer.

[icon] This section **needs expansion**. You can help by adding to it. *(April 2021)*

Fixed Plant

[edit]

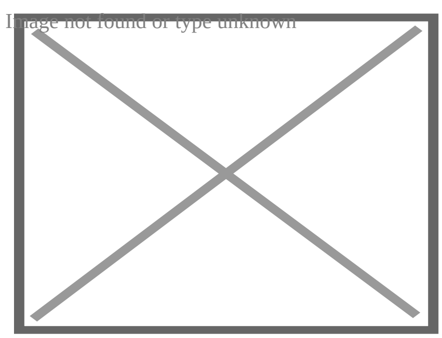


Towable EMSA Generator of Modiin Municipality

A **Fixed Plant Trailer** is a special purpose trailer built to carry units which usually are immobile such as large generators & pumps

Bicycle

[edit]
Main article: Bicycle trailer

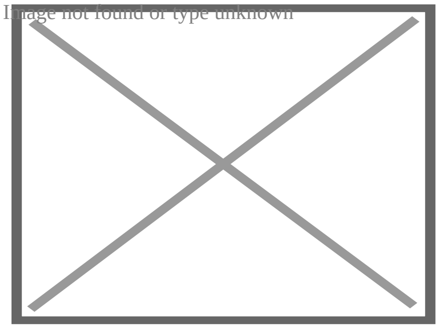


Bicycle trailer of Japan

A bicycle trailer is a motor less wheeled frame with a hitch system for transporting cargo by bicycle.[2]

Construction

[edit]
Main article: Construction trailer



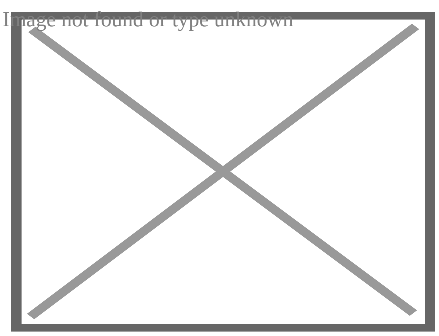
Construction trailer

Toilets are usually provided separately.[3]

Construction trailers are mobile structures (trailers) used to accommodate temporary offices, dining facilities and storage of building materials during construction projects. The trailers are equipped with radios for communication.

Travel

[edit]
Main article: Travel trailer



A custom-made popup camper trailer

Popular campers use lightweight trailers, aerodynamic trailers that can be towed by a small car, such as the BMW Air Camper. They are built to be lower than the tow vehicle, minimizing drag.

Others range from two-axle campers that can be pulled by most mid-sized pickups to trailers that are as long as the host country's law allows for drivers without special permits. Larger campers tend to be fully integrated recreational vehicles, which often are used to tow single-axle dolly trailers to allow the users to bring small cars on their travels.

Teardrop

[edit]
Main article: Teardrop trailer

Semi

[edit]
Main articles: Semi-trailer and Semi-trailer truck

A **semi-trailer** is a trailer without a front axle. A large proportion of its weight is supported either by a road tractor or by a detachable front axle assembly known as a dolly. A semi-trailer is normally equipped with legs, called "landing gear", which can be lowered to support it when it is uncoupled. In the United States, a single trailer cannot exceed a length of 57 ft 0 in (17.37 m) on interstate highways (unless a special permit is granted), although it is possible to link two smaller trailers together to a maximum length of 63 ft 0 in (19.20 m).

Semi-trailers vary considerably in design, ranging from open-topped grain haulers through Tautliners to normal-looking but refrigerated 13 ft 6 in (4.11 m) x 53 ft 0 in (16.15 m) enclosures ("reefers"). Many semi-trailers are part of semi-trailer trucks. Other types of semi-trailers include dry vans, flatbeds and chassis.

Many commercial organizations choose to rent or lease semi-trailer equipment rather than own their own semi-trailers, to free up capital and to keep trailer debt from appearing on their balance sheet.

Semi tank trailer in Japan

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  Semi tank trailer in Japan
- SinoTruk HOWO with flatbed trailer

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  SinoTruk HOWO with flatbed trailer

- LKW Kipper dump trailer

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  LKW Kipper dump trailer
  Sainsburys lorry refrigerated trailer

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  Sainsburys lorry
  refrigerated trailer
- A car carrier trailer

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  A car carrier trailer
- A truck pulling a semi-trailer using a trailer Dolly

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  A truck pulling a semi-trailer using a
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  Indian auto-rickshaw adapted with trailer

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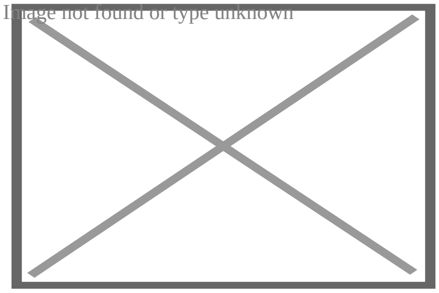
  adapted with *trailer*

Full

[edit]



Full trailer with steered axle

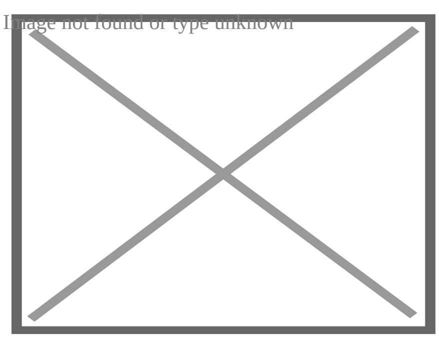
A **full trailer** is a term used in the United States and New Zealand[4] for a freight trailer supported by front and rear axles and pulled by a drawbar. In Europe this is known as an *A-frame drawbar trailer*, and in Australia it is known as a *dog trailer*. Commercial freight trailers are produced to length and width specifications defined by the country of operation. In America this is 96 or 102 in (2.4 or 2.6 m) wide and 35 or 40 ft (11 or 12 m) long. In New Zealand, the maximum width is 2.55 m (100 in) while the maximum length is 11.5 m (38 ft), giving a 22-pallet capacity.

As per AIS 053, full trailer is a towed vehicle having at least two axles, and equipped with a towing device which can move vertically in relation to the trailer and controls the direction of the front axle(s), but which transmits no significant static load to the towing vehicle. Common types of full trailers are flat deck, hardside/box, curtainside or bathtub tipper style with axle configurations up to two at the drawbar end and three at the rear of the trailer.

This style of trailer is also popular for use with farm tractors.

Close-coupled

[edit]



A close-coupled trailer

A close-coupled trailer is fitted with a rigid towbar which projects from its front and hooks onto a hook on the tractor. It does not pivot as a drawbar does.

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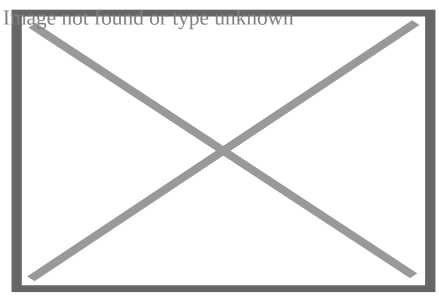
Motorcycle

[edit]
Main article: Motorcycle trailer



Interior of an enclosed motorcycle trailer

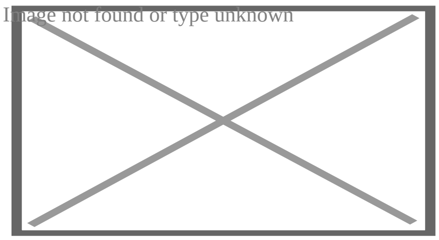
A motorcycle trailer may be a trailer designed to haul motorcycles behind an automobile or truck. Such trailers may be open or enclosed, ranging in size from trailers capable of carrying several motorcycles or only one. They may be designed specifically to carry motorcycles, with ramps and tie-downs, or may be a utility trailer adapted permanently or occasionally to haul one or more motorcycles.

Another type of motorcycle trailer is a wheeled frame with a hitch system designed for transporting cargo by motorcycle. Motorcycle trailers are often narrow and styled to match the appearance of the motorcycle they are intended to be towed behind. There are two-wheeled versions and single-wheeled versions. Single-wheeled trailers, such as the Unigo or Pav 40/41, are designed to allow the bike to have all the normal flexibility of a motorcycle, usually using a universal joint to enable the trailer to lean and turn with the motorcycle. No motorcycle manufacturer recommends that its motorcycles be used to tow a trailer because it results in additional safety hazards for motorcyclists.

Livestock

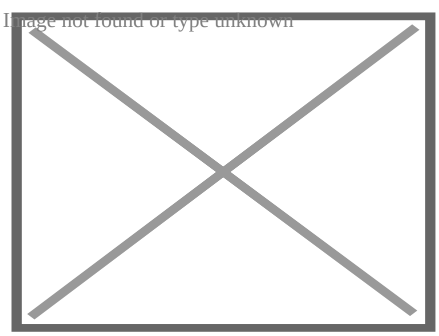
[edit]

See also: Horse trailer



A horse trailer

There are a number of different styles of trailers used to haul livestock such as cattle, horses, sheep and pigs. The most common is the stock trailer, a trailer that is enclosed on the bottom, but has openings at approximately the eye level of the animals to allow ventilation. The horse trailer is a more elaborate form of stock trailer. Because horses are usually hauled for the purpose of competition or work, where they must be in peak physical condition, horse trailers are designed for the comfort and safety of the animals. They usually have adjustable vents and windows as well as suspension designed to provide a smooth ride and less stress on the animals. In addition, horse trailers have internal partitions that assist the animal in staying upright during travel and protect horses from injuring each other in transit. Larger horse trailers may incorporate additional storage areas for horse tack and may even include elaborate living quarters with sleeping areas, bathroom and cooking facilities, and other comforts.



Lowe Boats Sea Nymph recreational fishing boat on a boat trailer

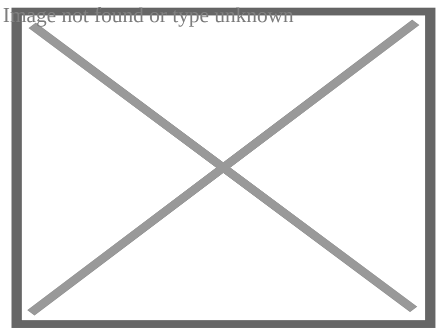
Both stock trailers and horse trailers range in size from small units capable of holding one to three animals, able to be pulled by a pickup truck, SUV or even a quad bike; to large semi-trailers that can haul a significant number of animals.

Boat

[edit]
Main article: Boat trailer

Roll trailer

[edit]

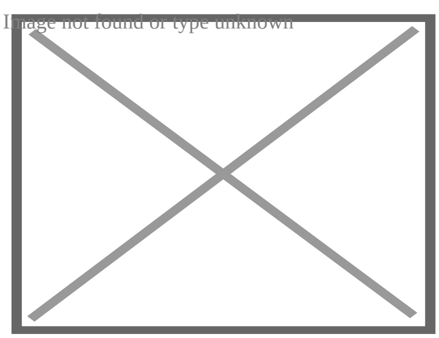


Maritime shipping Mafi Roll trailer

Main article: Roll trailer

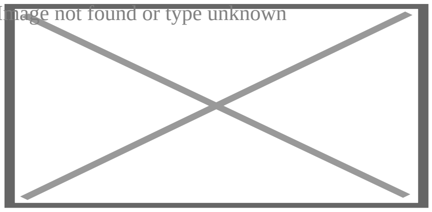
Baggage trailer

[edit]
Main article: airport dolly



A single trailer for an aircraft cargo unit load device, next to a group of trailers for loose luggage

Baggage trailers are used for the transportation of loose baggage, oversized bags, mail bags, loose cargo carton boxes, etc. between the aircraft and the terminal or sorting facility. Dollies for loose baggage are fitted with a brake system which blocks the wheels from moving when the connecting rod is not attached to a tug. Most dollies for loose baggage are completely enclosed except for the sides which use plastic curtains to protect items from weather. In the US, these dollies are called baggage carts, but in Europe *baggage cart* means passenger baggage trolleys.



Mammoet Tii Hydraulic modular trailer attached to a Mercedes ballast tractor moving front end loader

Hydraulic modular trailer

[edit]
Main article: Hydraulic modular trailer

A hydraulic modular trailer (HMT) is a special platform trailer unit which feature swing axles, hydraulic suspension, independently steerable axles, two or more axle rows, compatible to join two or more units longitudinally and laterally and uses power pack unit (PPU) to steer and adjust height. These trailer units are used to transport oversized load, which are difficult to disassemble and are overweight. These trailers are manufactured using high tensile steel, which makes it possible to bear the weight of the load with the help of one or more ballast tractors which push and pull these units via drawbar or gooseneck together making a heavy hauler unit.

Typical loads include oil rig modules, bridge sections, buildings, ship sections, and industrial machinery such as generators and turbines. There is a limited number of manufacturers who produce these heavy-duty trailers because the market share of oversized loads is very thin when we talk about transportation industry. There are self powered units of hydraulic modular trailer which are called SPMT which are used when the ballast tractors can not be applied.

Bus trailer

[edit]
Main article: Trailer bus

A bus trailer is for transporting passengers hauled by a tractor unit similar like that of a truck. These trailers have become obsolete due to the issue of the communication between the driver and the conductor and traffic jams.[*citation needed*]

Camel bus in Havana

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  Karosa NO 80 trailer bus
- Bus trailer in Lauterbrunnen

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  Bus trailer in Lauterbrunnen

Hitching

[edit]
Main articles: Tow hitch, Fifth wheel coupling, and Ringfeder

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Trailer-hitch on a large vehicle

A trailer hitch, fifth-wheel coupling or other type of tow hitch is needed to draw a trailer with a car, truck or other traction engine.

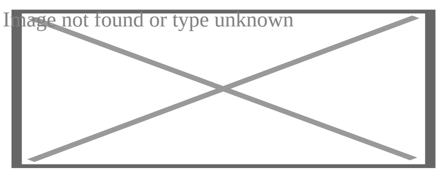
Ball and socket

[edit]

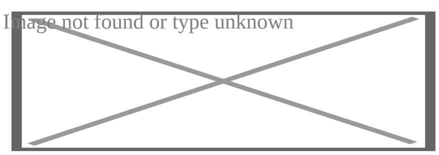
A trailer coupler is used to secure the trailer to the towing vehicle. The trailer coupler attaches to the trailer ball. This forms a ball and socket connection to allow for relative movement between the towing vehicle and trailer while towing over uneven road surfaces. The trailer ball is mounted to the rear bumper or to a draw bar, which may be removable. The draw bar is secured to the trailer hitch by inserting it into the hitch receiver and pinning it. The three most common types of couplers are straight couplers, A-frame couplers, and adjustable couplers. Bumper-pull hitches and draw bars can exert tremendous leverage on the tow vehicle making it harder to recover from a swerving situation.

Fifth wheel and gooseneck

[edit]



A gooseneck trailer attached to a pickup truck



Gooseneck trailer

These are available for loads between 10,000 and 30,000 pounds (4.5–13.6 t; 5.0–15.0 short tons; 4.5–13.4 long tons).[5][6] Both the hitches are better than a receiver hitch and allow a more efficient and central attachment of a large trailer to the tow vehicle. They can haul large loads without disrupting the stability of the vehicle. Traditional hitches are connected to the rear of the vehicle at the frame or bumper, while fifth wheel and gooseneck trailers are attached to the truck bed above the rear axle. This coupling location allows the truck to make sharper turns and haul heavier trailers. They can be mounted in the bed of a pickup truck or any type of flatbed. A fifth-wheel coupling is also referred to as a kingpin hitch and is a smaller version of the semi-trailer "fifth wheel". Though a fifth wheel and a gooseneck trailer look much the same, their method for coupling is different. A fifth wheel uses a large horseshoe-shaped coupling device mounted 1 foot (0.30 m) or more above the bed of the tow vehicle. A gooseneck couples to a standard 2+5?16-inch (59 mm) ball mounted on the bed of the tow vehicle. The operational difference between the two is the range of movement in the hitch. The gooseneck is very maneuverable and can tilt in all directions, while the fifth wheel is intended for level roads and limited tilt side to side. Gooseneck mounts are often used for agricultural and industrial trailers. Fifth-wheel mounts are often used for recreational trailers. Standard bumper-hitch trailers typically allow a 10% or 15% hitch load while a fifth wheel and gooseneck can handle 20% or 25% weight transfer.

Jacks

[edit]

The basic function of a trailer jack is to lift the trailer to a height that allows the trailer to be hitched or unhitched to and from the towing vehicle. Trailer jacks are also used for leveling the trailer during storage. The most common types of trailer jacks are A-frame jacks, swivel jacks, and drop-leg jacks. Some trailers, such as horse trailers, have a built-in jack at the tongue for this purpose.

Electrical components

[edit]

Many older cars took the feeds for the trailer's lights directly from the towing vehicle's rear light circuits. As bulb-check systems were introduced in the 1990s "by-pass relays" were introduced. These took a small signal from the rear lights to switch a relay which in turn powered the trailer's lights with its own power feed. Many towing electrical installations, including vehicle-specific kits incorporate some form of bypass relays.

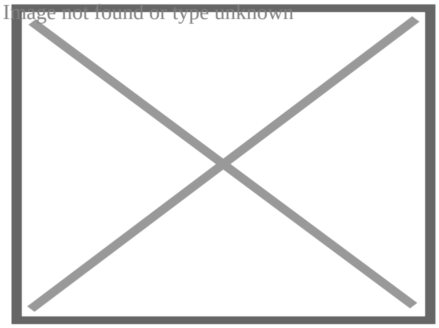
In the US, trailer lights usually have a shared light for brake and turn indicators. If such a trailer is to be connected to a car with separate lamps for turn indicator and brake a trailer light converter is needed, which allows for attaching the trailer's lights to the wiring of the vehicle.

Nowadays some vehicles are being fitted with CANbus networks, and some of these use the CANbus to connect the tow bar electrics to various safety systems and controls. For vehicles that use the CANbus to activate towing-related safety systems, a wiring kit that can interact appropriately must be used. Without such a towbar wiring kit the vehicle cannot detect the presence of a trailer and can therefore not activate safety features such as trailer stability program which can electronically control a snaking trailer or caravan.

By-pass systems are cheap, but may not be appropriate on cars with interactive safety features.

Brakes

[edit]



Bus and trailer in Saskatchewan, Canada

Larger trailers are usually fitted with brakes. These can be either electrically operated, air operated, or overrun brakes.

Stability

[edit]

Trailer stability can be defined as the tendency of a trailer to dissipate side-to-side motion. The initial motion may be caused by aerodynamic forces, such as from a cross wind or a passing vehicle. One common criterion for stability is the center of mass location with respect to the wheels, which can usually be detected by tongue weight. If the center of mass of the trailer is behind its wheels, therefore having a negative tongue weight, the trailer will likely be unstable. Another parameter which is less commonly a factor is the trailer moment of inertia. Even if the center of mass is forward of the wheels, a trailer with a long load, and thus large moment of inertia, may be unstable.[7]

Some vehicles are equipped with a Trailer Stability Program that may be able to compensate for improper loading.

See also

[edit]

- Electric vehicle battery
- Towing
- Tractor unit
- Trailer brake controller
- Vehicle category
- Walking floor

List of types of trailers

[edit]

- Bicycle trailer

- Boat trailer
- Bus trailer
- Compressed hydrogen tube trailer
- Construction trailer
- Dolly
- Dump trailer
- Enclosed cargo trailer
- Flat deck trailer
- Frac Tank
- Forestry trailer
- Genset trailer
- Horse trailer
- Hydraulic modular trailer
- Jeep trailer
- Liquid hydrogen trailer
- Lowboy (trailer)
- Mafi roll trailer
- Mobile home
- Motorcycle trailer
- Popup camper
- Pusher trailer
- Roll trailer
- Semi-trailer
- Solar trailer (for solar vehicles)
- Tautliner
- Tank trailer
- Travel trailer
- Food truck
- Mobile catering

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Frequently Asked Questions

What are the most effective techniques currently used for recovering rare materials from e-waste?

The most effective techniques include hydrometallurgical processes, pyrometallurgical methods, bioleaching, and advanced separation technologies like froth flotation and solvent extraction. These methods allow for the efficient recovery of metals such as gold, silver, palladium, and rare earth elements.

How do hydrometallurgical processes compare to pyrometallurgical methods in terms of efficiency and environmental impact?

Hydrometallurgical processes generally have a lower environmental impact compared to pyrometallurgical methods as they use aqueous solutions at lower temperatures. They can be more selective in extracting specific metals but may be less efficient in throughput time. Pyrometallurgy is faster and can handle larger volumes but often results in higher energy consumption and emissions.

What role does bioleaching play in the recovery of rare materials from e-waste?

Bioleaching uses microorganisms to extract metals from e-waste by oxidizing metal sulfides into soluble forms. It is considered an environmentally friendly alternative due to its low energy requirements and minimal chemical usage. However, it is typically slower than traditional methods and best suited for low-grade ores or residues where other techniques are not viable.

Are there any recent advancements in technology that improve the recovery rates of rare materials from e-waste?

Recent advancements include the development of more selective solvents for extraction processes, improvements in sensor-based sorting technologies that enhance material purity before processing, and innovations in electrochemical recycling techniques that increase recovery rates while reducing waste generation.

What challenges exist in scaling up these techniques for industrial-level e-waste processing?

Challenges include economic feasibility due to high initial investment costs, variability in e-waste composition which requires adaptable processing systems, regulatory hurdles related to waste management standards, and ensuring sustainable resource availability for reagents used in processing. Additionally, there is a need for improved logistical frameworks to efficiently collect and process large quantities of e-waste globally.

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