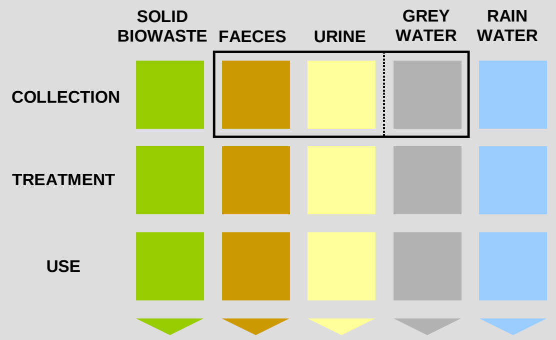
Vacuum Technology

(Low pressure systems)

Draft (30 Oct. 2009)



Preface and acknowledgements

Dear Reader,

This document is a revised version of the technical datasheets on “vacuum technology” which were published on the GTZ ecosan website in 2005. Authors of those documents were Florian Klingel, Christine Werner,Patrick Bracken, Ulrike Mosel and Sebastian Hass (in 2005 they were all working for the GTZ ecosan team).

To be updated!

The GTZ ecosan team hopes that you find this publication useful for your own ecosan projects and dissemination activities. If you spot omissions, errors or confusing text, please e-mail us your feedback at ecosan@gtz.de.

Kind regards,

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1 General Description

1.1 Basic principles

The vacuum technology is applied as a sewage collection tool in ships, trains and aircrafts for years. But it can also be used in domestic technology for wastewater, especially e.g. with the anaerobic digestion of the high-concentrated blackwater (see technical data sheets for anaerobic treatment). Domestic technology can be divided into two main fields of application: vacuum sewer systems and vacuum sanitary installations.

According to the circumstances these two systems can be technically combined with each other or they can work alone.

Wastewater is transported in a low-pressure system by using air instead of water as transport medium. A vacuum toilet needs only approximately 1l of water per flush, thus extreme water savings up to 80% can be reached. The low dilution of the excreta allows a more concentrated collection than gravity systems do.

Thus integrated ecological concepts can be realized: The system offers the opportunity of split-stream collection due to the possible separate compilation of blackwater and greywater, use of the treated greywater for irrigation or ground infiltration, anaerobic treatment of the concentrated blackwater including biogas production and power generating and subsequently end use of the bio sludge products as a valuable fertilizer. Unnecessary dilution of the flow streams is avoided, this minimises the consumption of valuable drinking water and produces high concentrations of recyclables.

The system components are a central vacuum station, generating the low pressure; the vacuum sewer lines, in which the wastewater/air mixture is transported and interface units, connecting the vacuum system to the non vacuum components.

1.2 Available technologies

Vacuum technology is mainly applied in decentralized sewerage schemes and for sanitary installations in building services engineering.

In urban drainage vacuum technology is a possible alternative to separate sewer systems, where stormwater is discharged separately. It consists of collection chambers, sewers and a vacuum station. Vacuum sanitary installations consist of vacuum toilets, interface units for all kind of fixtures (showers, bathtub, washbasin, urinals) and piping. In cases of large scale application there also has to be a central vacuum station, for small scale application a special kind of vacuum pump is absolute sufficient.

1.3 Applicability

Vacuum technology is a high tech solution and offers the opportunity to keep the high standard in urban drainage and bathroom equipment, thus the users don't need to change their habits. Of course it requires correct construction, maintenance and damage control. If these conditions can't be guaranteed, the system appears inadequate!

Vacuum sewerage systems are not likely to replace gravity sewers in general, because of their necessity to be operated and designed in a sophisticated way. Mechanical installations are more likely to break down than simple sewerage structures. Nevertheless, in many situations, the advantage offered by vacuum sewer systems will justify their applications.

Favourable application conditions for vacuum technology:

Vacuum sewerage:

- Sparsely populated, ribbon areas, especially in hilly terrain
- Seasonal settlements
- Water scare regions
- Flat terrain
- Rocky soil, high groundwater table

Vacuum sanitary installations:

- High water price regions
- Water scarce regions
- Difficult construction conditions
- Nutrient and energy recycling desires (anaerobic treatment)

As no spooling is necessary in those systems, they have a main advantage. A special application field for this kind of systems is also located at water protection areas.

One should also consider that vacuum sewerage could only substitute a separate sewer system, i.e. stormwater has to be discharged in another sewer line or be infiltrated or used locally. Hydraulically speaking, vacuum systems are limited somewhat by topography.

The vacuum produced by a vacuum station is capable of lifting wastewater 4.5 to 6.0 m. The sewers can only reach up to 2-4 km; otherwise several vacuum stations are needed.

Table 1: Evaluation of vacuum technology

	Strengths	Weaknesses
Health impact	• No leakage • Highest hygienic safety (closed system) • No pathogen contamination of the groundwater • Reduction of wastewater flows through sewers and wastewater treatment plants	
Environmental impact	• Tool for integrated ecological concepts such as energy recovery (biogas) from blackwater possible • High security against leakage of wastewater (no nutrient and pathogens) • Water savings up to 80% for vacuum toilet flushing • Reduction of wastewater flows through sewers and wastewater treatment plants	• Additional energy for operation required
Socio-cultural suitability	• High Tech provides the same comfort than gravity • No odour nuisance	• Correct construction, operation and maintenance required
Costs and benefits	• 20 to 25% cheaper than conventional sewerage due to easy construction without heavy machinery • Due to water saving amortisation for vacuum sanitary installations within few years possible	• Vacuum sewer require about 10 to 30kWh/p.a) • Vacuum sanitary installation require about 4 kWh/(p.a) and cause 40% higher investment cost
Technical suitability	• Ductile, lightweight material, ease of installation and handling • No slope requirements • Shallow and narrow trenches • High flexibility according to appearing obstacles	• Correct construction, operation and maintenance required • High Tech to power breaks

2 Vacuum Sewer Systems

2.1 Functional principles

Briefly explained, vacuum sewerage means that in a central vacuum station a low pressure of about –0.6 bar is created by at least two vacuum pumps. The wastewater from the houses is held back in collection chambers (Figure 1), with pneumatic regulating valves (1), close to the houses.

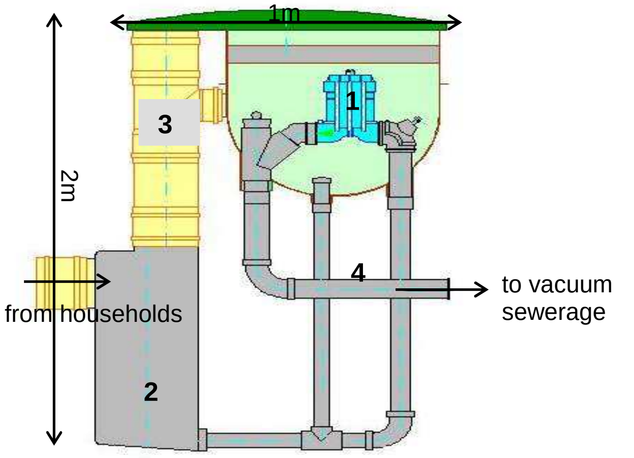

Figure 1: cross section of collection chamber with membrane valve (*ROEDIGER, 2002*)

When a given volume of wastewater is collected in the chamber sump (2), a pneumatic controller (3) is activated by hydrostatic pressure. The controller opens an interface valve (1) for an adjustable time period. The wastewater (10 to 50 l) and a certain amount of air (20 to 60 l) are evacuated through the open valve into the vacuum sewer line (4). The pressure gradient between the vacuum station and atmospheric pressure at the collection chambers is responsible for the movement of sewage to the vacuum tank. The vacuum mains discharge into a collection tank at the vacuum station. By use of sewage pumps, sewage will be transported to treatment facilities or into a conventional system afterwards. The exhaust air can be further treated in bio filters, consisting of bark and wood.

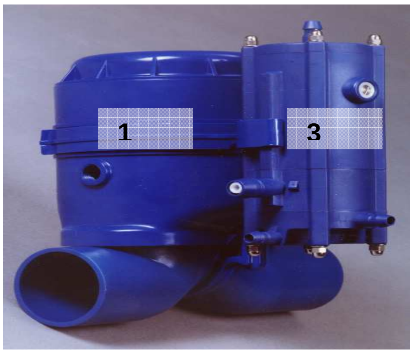

Figure 2: Pneumatic diaphragm valve 65mm (1) and controller (3) (*ROEDIGER, 2002*)

The sewers are passed in specific profiles, in saw-tooth-pocket or wave profile with significant high and low points. Wastewater comes to rest at the low points and forms plugs. The system works like a pneumatic tube conveyor:

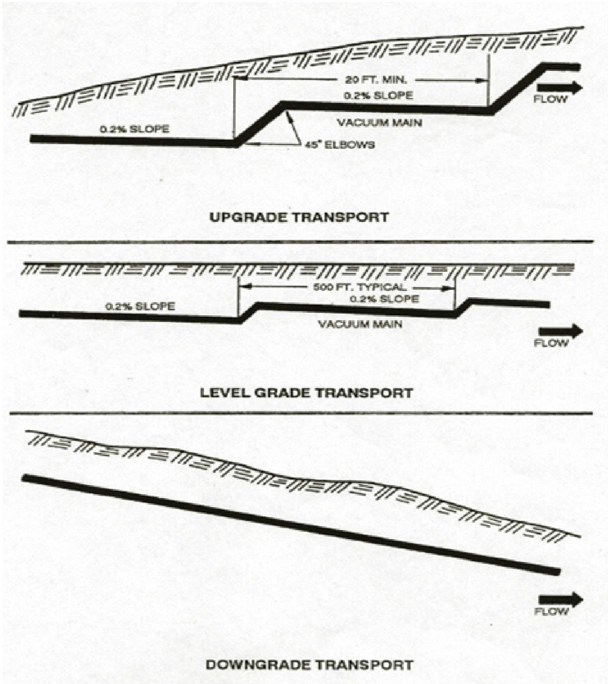

Figure 3: passing procedure depending on surface conditions (*AIRVAC*)

it's even possible to negotiate jumps. When air is admitted through an upstream interface valve, these plugs are accelerated and pushed over the high points towards the vacuum station.

The vacuum station is the heart of the vacuum sewer system. Wastewater and air enter the vessel from the vacuum sewer. The wastewater is collected in the vessel and if a certain volume is reached (mostly 25 % of the tanks volume) it is discharged to wastewater treatment plants or to conventional sewer by sewage pumps.

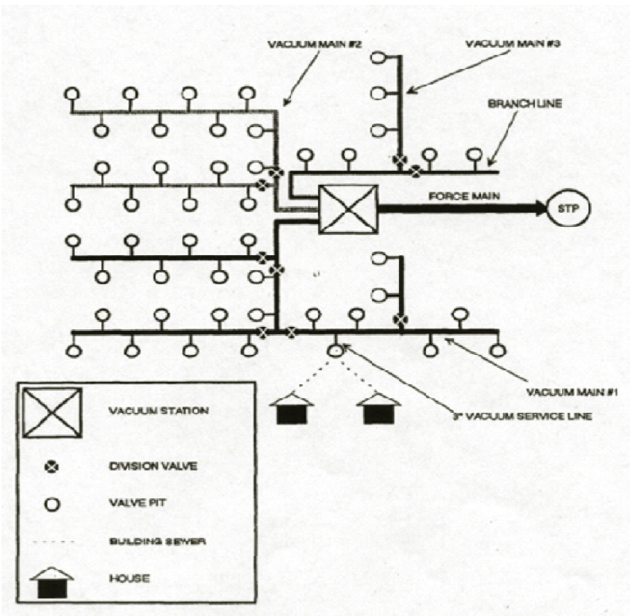

Figure 4: vacuum sewer system (*AIRVAC*)

2.2 Operation and maintenance

The vacuum sewerage is a High-tech Technology and requires of course correct construction, maintenance and damage control. If these conditions are guaranteed, the system is reliable and nearly maintenance-free. Due to the turbulent flow, blockages won't appear. Continuous aeration prevents deposits, odours and the septic actions. Thus flushing of the sewer is not necessary. Maintenance and electricity consumption are limited to the vacuum station, and thus concentrated in one location. Due to the low pressure inside the pipes, leakages won't occur. It's even possible to pass the pipes in the same trench as the drinking water main.

Table 2: Life expectancy of system components in Years (ATV-DVWK, 2004).

System components	Years
Vacuum vessel	25 to 40
Collection chambers	30 to 55
Vacuum pumps	20 to 30
Piping system	50 to 80
Sewage pumps	12
Pneumatical interfaces	30

Due to the under-pressure in the reticulation pipe system, an extended pump run time will be an indicator for the damages cause to pipes, unlike in gravity systems where leakage can only be noticed by sewer monitoring. Thus control and maintenance of the valves and the piping is not essential.

Access to pipes can be gained at each collection chamber. In order to isolate particular section for trouble shooting or repairing, division valves are installed on every major branch connection and on the mains. Inspection pipes, installed at distances of approx. 100 m permit insertion of inflatable balls and precise locating of leaks. Any person with basic technical knowledge can operate a vacuum system. High school education is absolutely adequate[1].

Only the pumps in the vacuum station need electrical power (10 to 30 kWh per inhabitant per year) and maintenance ca. once a year, the vacuum station should be visited once a week carrying out a visual inspection, which lasts about one hour[2].

Material used in bio filters (wood, bark) should be changed every two to three years.

An emergency generator is necessary in case of frequent power cuts to prevent prolonged pump failure and breakdown of the vacuum system.

2.3 Extent of application

Vacuum sewerage is not a new technology; it's actually a state of the art. The beginnings of this today's widespread special drainage procedure started around 1860 when the Dutch engineer Liernur used such systems for the first time. In the sixties of the 20th Century the Swede Liljendahl took up the ideas by Liernur again and developed them further. The system was rapidly improved and its reliability

[1] AIRVAC, Overview of alternative conveyance systems
[2] Own notes, sketches from company excursions, own conversations

was crucially increased. By the use of plastic pipelines in 1970 a new spreading wave was released worldwide. A further large thrust for the intensified application of the vacuum drainage took place in Germany with the entrance of further suppliers of evacuated system in the middle of the 90's. (In this period the main components interface valve and pumps were reduced in price around ca. 40 %.) Thereby the vacuum sewerage also became interesting for ranges that were reserved for the gravity sewerage so far (VAB Vakuum Anlangen Bau GmbH, 2003). Worldwide there are today five suppliers of vacuum sewer systems.

The system has been grown out of its infancy; vacuum sewerage can be applied all over the world in every elevation, if certain conditions are given. Vacuum sewerage lends itself ideally to rural areas, coastal areas, lakesides, flat terrain, briefly, anywhere where difficult terrain would make conventional gravity system with pumping stations too expensive.

It is especially suitable for areas with high groundwater table (lakes, rivers and coasts, where flooding can occur) or where water protection areas might be crossed. Vacuum technology is also interesting where the wastewater flow is low or varies in a wide range e.g. in resorts. Even when the flow is less wastewater is kept fresh due to aeration and relatively low periods of staying in the pipes. In densely populated areas, vacuum technology is not an economical substitute for gravity systems due to the high wastewater volume and thus extended pump run times. Vacuum technology is not suitable where longer transport sessions over 4 km become necessary.

The suitability vacuum sewer system depends on (ROEDIGER, 2002):

- Low density population settlement
- Decentralised or semi-decentralized sanitation systems
- Insufficient natural slope, i.e. flat topography
- Poor subsoil conditions (i.e. unstable soil or rock, high groundwater table, complicate excavation)
- Obstacles to the sewer route
- Aquifer protection zones
- Seasonal operation (e.g. holiday resorts)
- Minimal space for infrastructure installations
- Water sensitive areas (lakes, rivers and coasts, or where flooding can occur)

2.4 Economical data

Under difficult technical and topographical conditions vacuum sewerage systems are quite cheaper than conventional sewerage. If the costs for conventional systems would exceed 2000 EUR/P vacuum sewerage should be taken into account (VAB Vakuum Anlangen Bau GmbH, 2003). Experiences have also shown that a minimum of 75 – 100 customers is needed to be cost effective[1].

Table 3: Installation costs Shoshong, Botswana[3]

Component	Quantity	Price [EUR]
Vacuum station	1	88,480
Collection chambers	40	60,000
Sewer line	4.400m	88,366

Vacuum sewers are 20 to 25 % less costly to construct than conventional sewers due to cost savings listed below.

Capital/Operational costs saving due to (ISEKI REDIVAC, 2004):

- Narrow and shallow trenches (1.0 to 1.4 m)
- Low diameter of sewer (65 to 250 mm)
- Efficient construction period
- No requirement for manholes
- No requirement to clean or remove sediments from within the vacuum sewers
- Pump sizes and subsequently electrical power consumption are significantly reduced concerning no groundwater infiltration
- Elimination of infiltration allows a reduction of sizes and costs of the treatment plant.

A collection chamber costs about 1500 EUR, about 850 to 900 EUR without installation[2]. A Vacuum station is available from 20,000 to 100,000 EUR depending on size. The electricity consumption varies between 10 to 30 kWh/(P•a).

2.5 Design information

Collection chamber

The collection chamber consists of polyethylene high density (PE-HD) or glass reinforced plastics (GRP) and it contains one membrane (see figure 2) or piston interface valve (see figure 8), which is pneumatically regulated. Ventilation for the correct air/liquid ratio varies between 3:1 and 15:1 and is adjusted by the system supplier. The collection chambers are installed under driveways, paths, roads or even under gardens.

Figure 5: collection chamber

[3] Draft proposal of water conservation installation and rainwater harvesting at the College of technical vocational education Francistown technical College.

Figure 6: vacuum sanitation with buried vessel

Sewer

The length of the sewer mains varies between 2 to 4 km, they should be declined at least with a slope of 0.2 % towards the vacuum station. The lifts are installed every 6m to 100m, depending on the laying procedure and topography (see figure 3). Pipes are made of PE-HD or polyvinyl chloride (PVC); both can be glued and welded. Common diameters are 65 mm to 200 mm. The flow velocity of the plugs is between 4 m/s and 6 m/s.

Vacuum station

The vacuum station should be located next to a conventional sewer or wastewater treatment plant and if possible at a low point. The constructional design can be variable, e.g. as monolithic or stonewalled construction up to blockhouses.

The most common type is a buried steel vessel due to water tightness, volumes range from 5 to 25 m³. The stations and collection chambers should be protected against lifting just as arrangements for noise and odour protection should be met. A bio filter lends itself to exhausted air deodorization. Furthermore the vacuum station consists of at least two vacuum and sewage pumps, which are usually rotary vane or rotary piston pumps. The sewage pumps forward the wastewater automatically to the gravity sewer or directly to the wastewater treatment plant.

Detailed information on construction can be found in the ATV A 116, see B.1.7.

Figure 7: Prefabricated compact vacuum station (*Mosel*)

Figure 8: vacuum operating valve (*QUAVAC*)

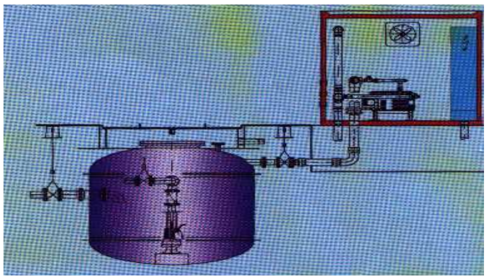

Figure 9: vacuum station with an external buried steel tank. Vacuum pumps are in the house (*ROEDIGER, 2002*)

2.6 Strengths and weaknesses

Health impact

The probability of pathogen pollution of the groundwater is very small due to no wastewater leakage.

Environmental impact

There is almost no opportunity for nutrient leakage into the soil and the groundwater; therefore vacuum systems can be used in groundwater protection areas. Vacuum sewerage lends itself as a tool for integrated ecological concepts. Compared to conventional sewer system it does not depend on a minimum wastewater volume, in order to transport suspended solid. Water consumption may therefore be reduced and no water would be required for flushing the sewers.

Vacuum sewerage allows the transport of a more concentrated wastewater than gravity systems do. A high potential for treatment and recycling of low-diluted flow streams exists. As an example, vacuum sewers may be especially useful in ecosan systems to collect low-diluted blackwater or brownwater only, which could be treated in an anaerobic digester producing biogas and fertilizing sludge.

Operating the systems requires energy input for the vacuum pumps.

Costs and benefits

Compared to gravity drainage there may be lower investment costs due to the facts mentioned under 2.3 on page 6. Furthermore vacuum technology is more flexible and more appropriate in areas with seasonal fluctuations. Repairs and cleansing are less costly than for conventional systems.

Socio-cultural suitability

The vacuum sewerage provides the same comfort for wastewater evacuation as gravity sewerage.

There are no differences in application for the user compared to conventional sewerage. If a breakdown occurs the storage capacity provided by the service pipe prevents overflowing into the basement. Initially there may be some concerns regarding the vacuum technology, but first experiences have shown that once the system is applied, the acceptance will increase. (See project data sheet Botswana, Shoshong)

Fewer accidents occur during the construction periods due to shallower trenches. The regional contractor can be easily involved in the installation of this system and all the civil work can be done without heavy excavation equipment and blasting.

Otherwise measures for noise protection and odours should be done.

Technical suitability

The vacuum sewerage is a High Tech solution and technically more challenging than gravity, on the other hand it is easy to construct due to the use of ductile and lightweight material and there is a high flexibility in the construction period according to obstacles granted. The complexity of operation and maintenance compared to gravity drainage is less, but the pumping energy is required, thus the system is vulnerable to power breakdowns and failure of technical or other assets.

3 Vacuum Sanitary Installations

Vacuum sanitary installations are applicable where:

- drinking water is scarce, or where water consumption needs to be reduced for environmental or costs reasons
- sewers or WWTP`s are non-existent or overloaded
- sanitary facilities are frequently used and the water bill is high
- insufficient slope, lack of space, low ceilings, or other structural limitations make gravity drainage impossible or difficult
- reconstruction, modernization or modification of existing structures is difficult or expensive
- separate grey and blackwater treatment is required or desired, e.g. for reuse in ecosan systems
- wastewater has to be transported from many distant places to a central location

3.1 Functional principles

Vacuum sanitary systems use the basic physical principle that air pressure gradients can generate rapid airflow. Two types of vacuum systems can be realized, depending on quantity of the connected components. For small scale application like cottages it's called vacuum on demand (VOD) and for large building complexes such as hotels, business parks and factories there are systems with a constant vacuum (CVS).

Key components of a CVS are a vacuum station (consisting of vacuum and sewage pumps, vessel and control panel), vacuum toilets and interface units, see figure 14. The vacuum pump (mostly two) on the top of the vessel generates sub-atmospheric pressure within the vacuum tank. Wastewater is evacuated from vacuum toilets or interface units, which are used to connect washbasins, bathtubs, sinks and showers, and is collected in the tank. The wastewater pump discharges the wastewater from the vacuum tank to a decentralized or semi-decentralized treatment unit or to the municipal sewer system. A level sensor, integrated in the tank, controls the operation of the wastewater pump.

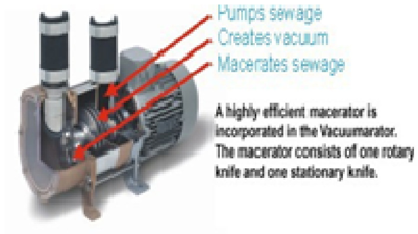

Figure 10: vacuum pump for VOD systems (www.jets.no, 2004**)**

The VOD principle is based on having no vacuum in the pipeline unless someone activates the flush button. The toilets are connected to a specific kind of pump which in one operation evacuates the wastewater and discharges it to the public gravity sewer or to a kind of storage tank, if further treatment is required, see figure 10 and figure 13.

The vacuum toilet works in the following way: After use of the toilet, flushing (0.7-1.2 litre/flush) is triggered by pushing a button. The interface valve is opened when the button is released and the blackwater (urine separation vacuum toilets are not yet available); together with a volume of 10 to 50 litres air is evacuated through the vacuum lines to the system tank.

It is possible to collect the greywater together with blackwater or separately via an additional gravity or vacuum system. The latter allows the separate treatment of the blackwater and greywater. The blackwater is thus only little diluted and highly concentrated, which offers good anaerobic treatment conditions and allows the production of biogas for energy production and of digested sludge serving as a nutrient rich soil conditioner.

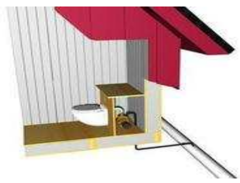

Figure 11: VOD with discharge to public sewer (www.jets.no, 2004)

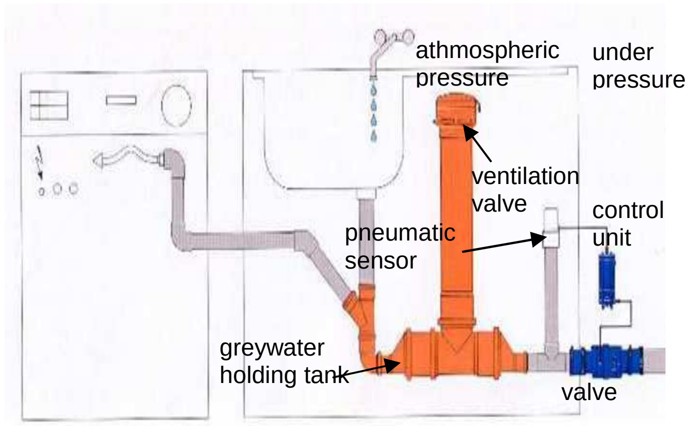

Figure 12: Example for connection of a washbasin and dishwasher to the vacuum system. The greywater is collected via gravity in a holding tank; if a certain volume is reached a pneumatic sensor is activated by hydrostatic pressure. The control unit opens a pneumatic valve for an adjustable time period. The greywater and some air is evacuated through the open valve into the vacuum collection line (*ROEDIGER, 2002*)

Figure 13: VOD with discharge to collection tank (*www.jets.no*, 2004)

If greywater from showers sinks, washbasins and bath tubes is to be collected by the vacuum system, it first has to be collected in pneumatically regulating interface units until a certain volume is reached. Afterwards it is automatically evacuated in the vacuum sewer line towards the vacuum tank, see figure 12. Depending on the system, greywater from the kitchen, which is relatively rich in organic matter, may also be collected together with blackwater for anaerobic treatment.

3.2 Operation and maintenance

The vacuum toilets are used in the same way as flush toilets; only the flushing system and noise are different.

In CVS the piping system is constructed in a kind of saw-tooth profile, following the same principle like vacuum sewerage. Every 25 to 30 m there are significant high and low points, where wastewater comes to rest and forms plugs.

The interfaces have to be installed in a manner that provides easy access in cases of troubleshooting.

Regular inspections of the toilets and the vacuum station ca. once a week minimize the risk of breaks and blockings and is absolute adequate.

Due to the under-pressure in the pipe system, an extended pump run time will indicate every damage of pipes, thus control and maintenance of the valves and the piping is not essential.

In fact mechanical blocking of the pipe won't occur, as nearly every kind of waste that is smaller than the valve diameter can be evacuated through the sewer lines. However, the vacuum vessel has to be inspected regularly, as bulky waste will accumulate here. Whole jeans and t-shirts have been reported to having been found in the vacuum vessel. Lime and urine precipitation is possible. Thus some vacuum technology supplier offer effective solutions (GREEN BIO CLEAN®) against such deposits. The caretakers need a special education.

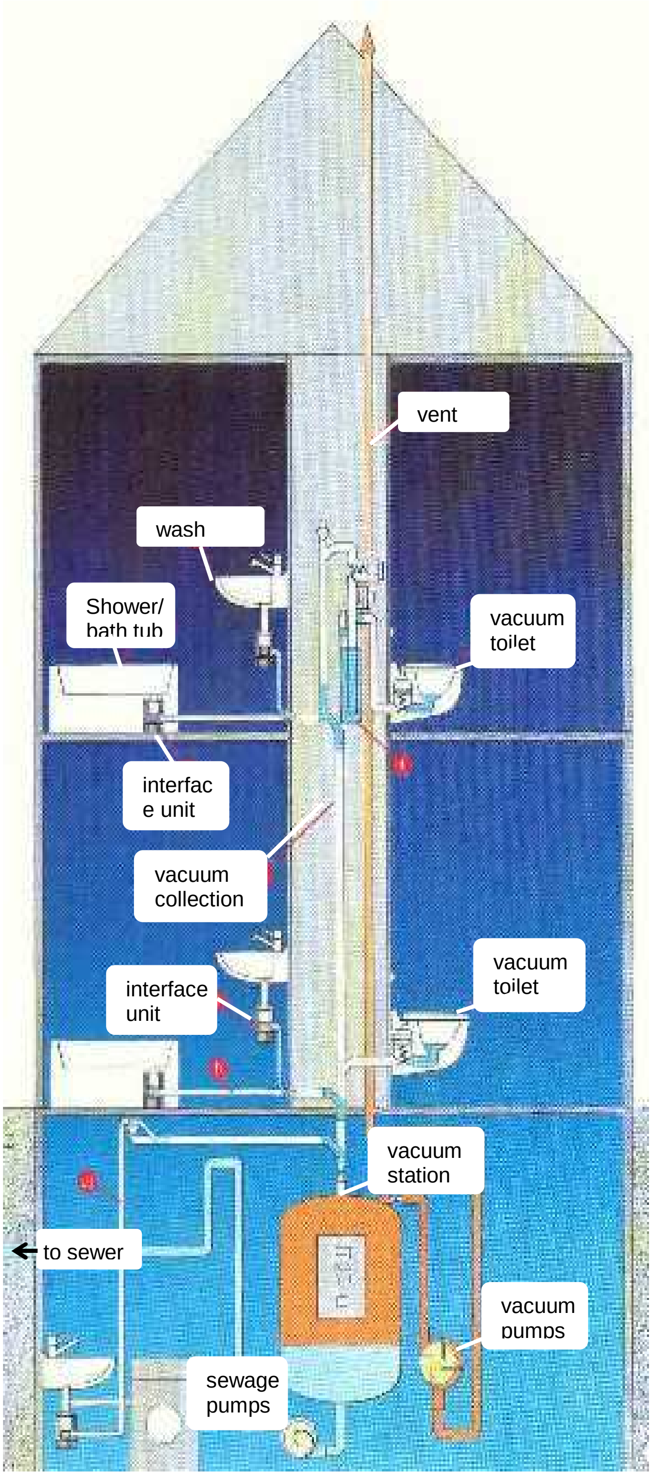

Figure 14: Components of a CVS (*ROEDIGER, 2004*)

3.3 Extent of application

About 40 years ago the development of sanitary installations starts with the aim of getting a more economic solution by saving water and reducing the construction costs. The flexibility in placement and installation improved the further development. Ten years later the implementation and development in aviation, marine and railway industry began because of the great advantages in weight, space and cost savings that are a very important cost factor in these industries. Nowadays airplanes, ships and trains are unimaginable without vacuum sanitary installations.

Vacuum sanitary installations can be used worldwide. But the high investment costs compared to conventional flush systems and limited manufactures of the components prevented a wider spread. The dependency on continual power supply makes this technology sometimes unsuitable in developing countries. At the moment there are some plants in Germany, Portugal, China and Tunisia.

Another range of operation is the equipping of trains and ships with exhausting systems (suction removal) for wastewater and vacuum stations. This ensures a rapid and hygienic disposal of wastewater by means of vacuum transportation.

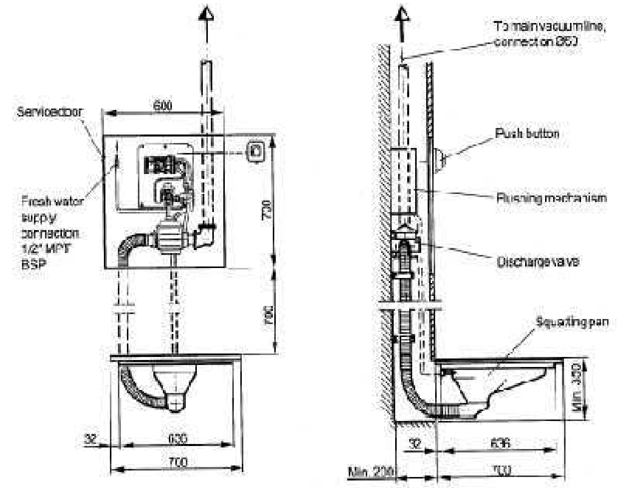

Figure 15: EVAC 90, squatting model (EVAC product catalogue, 2004)

Further application is in nuclear medicine departments within hospitals, which have radioactive wastewater to discharge. Due to government regulations, radioactive wastewater may only enter sewerage systems once the radioactivity has decayed. For this purpose delivers e.g. ROEDIGER custom tailored solutions, i.e., decay holding tanks, which are distinguished through special water saving technologies. Due to the lower wastewater volumes, total investment and handling costs are reduced significantly.

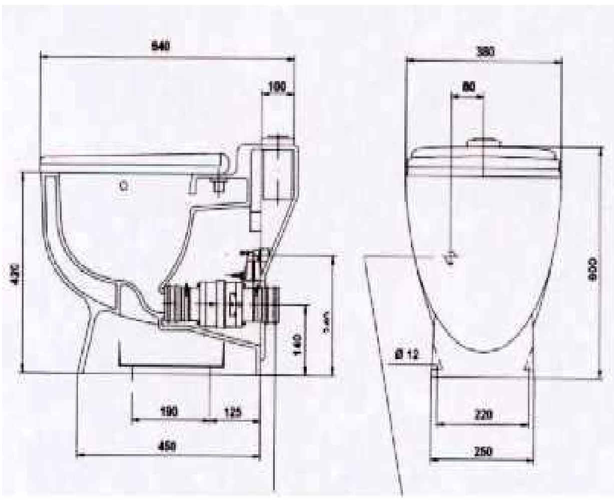

Figure 16**:** ROEDIGER Vacuum toilet floor mounted (*ROEDIGER, 2004*)

3.4 Economical data

The complete system costs depend on the length of the necessary pipes, the difficulty of the installation and the case in which this technology is implemented it's a difference if the integration must be done in a finished building or the implementation can be done during the planning phase of a new construction.

In general the investment costs are about 40% higher than for a conventional system due to the higher costs for the vacuum toilets and the vacuum station.

Due to the reduction of water consumption and wastewater an amortisation is possible within a couple of years, when water and wastewater prices are high (in Germany e.g. approximately 4 EUR/m³).

3.5 Design information

Vacuum toilets

Vacuum toilets are available in different versions. As wall- (see figure 16), floor- or even squatting (see figure 15) model in sanitary porcelain, plastic or stainless steel. The surface of the entire bowl is absolutely smooth. ROEDIGER substitutes the unhygienic flush water groove by flush water nozzles.

Interfaces

Interface units are small and can be mounted directly under sanitary fixtures (e.g. wash basins). They can be installed in a wall from where they are connected with the sanitary appliances through short gravity lines. This allows furthermore easy access in cases of troubleshooting.

Piping

The used pipes are generally smaller than pipes used for conventional flushing systems. E.g. vacuum service lines: 40 mm, vacuum collection lines: 50 mm, main collection lines: 70 mm. Check valves must be integrated in front of every joint and ball valves are installed in every wet room. Available materials are PE-HD and PVC in toilets, cast iron pipe and zinced steel pipe in main pipes (hall and installation pits).

Vacuum station

The collection tank is mostly made of steel only small ones are made of PE with a volume up to 3m³. The number of connected units to a station should not exceed 90 interfaces.

3.6 Strengths and weaknesses

Health impact

The usage of vacuum sanitary installations is as hygienic and odourless as a flush system. It is a matter of a closed system, no leakage occurs due to the under pressure and thus the user won't get in contact with the sewage.

Environmental impact

Compared to flush toilets a reduction of water consumption up to 80 % is possible. The result is a reduction of the wastewater flow through sewers and the wastewater treatment plant and a concentrated blackwater flow that can be used for biogas production in anaerobic treatment and for subsequent agricultural use as a nutrient rich irrigation water or sludge.

If washbasins, showers or bathtubs are separately connected via gravity or an additional vacuum pipe, 'recycling' of undiluted blackwater by means of anaerobic treatment in biogas plants is possible. But today in most cases a second pipe system is missing so the greywater is mixed with blackwater.

Socio-cultural suitability

Due to the fact that there's only a small difference to a gravity flush toilet the acceptance of vacuum systems will be high after a short period of living with it. Only the flushing noise is louder compared to conventional systems. Thus measures for noise protection have to be done. E.g. the suction of air through a separate pipe behind the wall is currently tested by ROEDIGER. Thus would respectably decrease suction noises.

Some problems could appear in cultures where anal washing is practiced. Flooding of the toilet bowl could occur due to no continuous run-off. An alternative could be that the toilets have to be equipped with an electrical control system that automatically and regularly flushes the bowl, but a satisfying solution is not yet available.

Technical suitability

Vacuum technology is technically more challenging than conventional gravity systems, thus it requires correct construction, maintenance and damage control. Compared to the complexity of planning and constructing of conventional gravity systems the vacuum systems have the advantages that nearly no slope is required, an upward evacuation is possible and obstacles can be by-passed (that allows easy later extensions).

Costs and benefits

The initial installation costs of a vacuum sanitary installation are higher than for a conventional gravity flush systems due to the high costs of the vacuum station and the toilet units. Otherwise the initial planning costs are the same. Savings through reduction of water usage and lower maintenance costs allow amortisation where water prices are high although more energy to operate the pumps is required.

Another advantage is that later extensions are normally cheaper than for a conventional system because of the smaller diameter and the flexibility of the pipes.

3.7 Good practice examples

- KfW (see project data sheet)
- Lübeck Flintenbreite
- Vauban
- Shoshong (ROEDIGER)
- Gabarone, Botswana: decentralized vacuum system (Roediger GmbH). See the Fig:-

Figure 17**:** Formula 1 Speed way in China (*RODEGIER*)

4 References

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VAB Vakuum Anlagen Bau GmbH, 2003, *Einweisung zum Bau von Vakuumentwässerungsanlagen nach dem system VAB/AIRVAC.* http://www.vabgmbh.com/images/Einweisung_zum_Bau.pdf

4.1 Further reading

Complex literature about it hardly exists; designing concepts are mostly based on company internal empiric data.

ATV-DVWK-A 116 „Besondere Entwässerungsverfahren, Teil 1: Unterdruckentwässerungssysteme außerhalb von Gebäuden"

ATV-DVWK, D-53773 Hennef, 2004

Project work by Lars Späth "The Potential of Vacuum Sewerage as an Alternative in Communal Wastewater Collection Systems"
Lars Späth, D-76128 Karlsruhe, 1998
European Standard EN 1091 „Vacuum Sewerage outside buildings" DIN Deutsches Institut für Normung e.V., Berlin, 1999

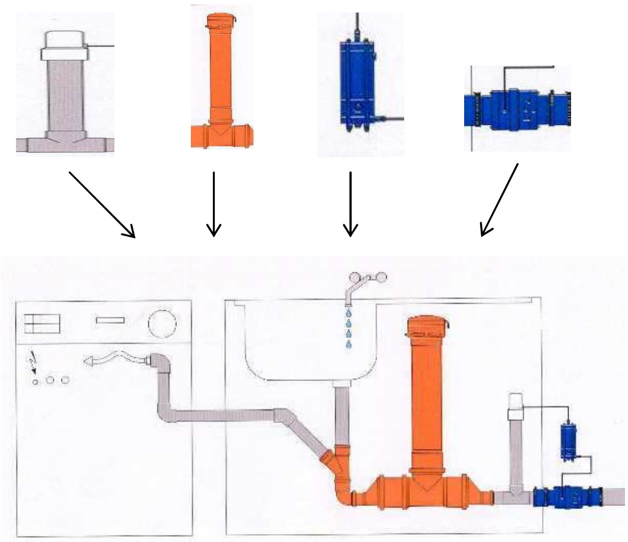
Only in Danish available:

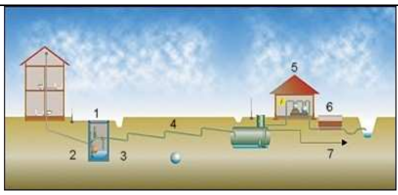
Miljøministeriet, Økologisk byfornyelse og spildevandsrensning N.36: "Vakuumtoiletter og behandling af det indsamlede materiale i biogasanlæg eller vådkomposteringsanlæg" (Arne Backlund, Annette Holtze; 2003, http://www.backlund.dk/projekte.htm)

5 Appendix A: Vacuum sanitary installation options

	Components	Features	Manufacturer/Contact
Vacuum Toilets	JETS 50 EFD 	▪ 20,2 kg to 22, kg ▪ wall or floor mounted ▪ electrical operation ▪ vitrous china, sanitary porcelain ▪ 0,5 l to 1,5 per flush ▪ 350 - 450 EUR	**JETS Vacuum AS** P.O. Box 14, N-6069 Hareid, Norway Phone: + 47 70 03 91 00 Fax: + 47 70 03 91 01 post@jets.no www.jets.no
	JETS 60 EFD 	▪ for ships ▪ 19 kg ▪ stainless steel ▪ X EUR	**JETS Vacuum AS** P.O. Box 14, N-6069 Hareid, Norway Phone: + 47 70 03 91 00 Fax: + 47 70 03 91 01 post@jets.no www.jets.no
	JETS Squat pan 	▪ stainless steel ▪ x EUR	**JETS Vacuum AS** P.O. Box 14, N-6069 Hareid, Norway Phone: + 47 70 03 91 00 Fax: + 47 70 03 91 01 post@jets.no www.jets.no VOD systems for cottages, CVS for larger buildings.
	ROEDIGER 	▪ tube valve ▪ wall or floor mounted ▪ pneumatic operation ▪ porcelain ▪ 0,7 l per flush ▪ 590 - 645 EUR	**ROEDIGER VAKUUM HAUSTECHNIK GmbH** Kinzigheimer Weg 104-106 D-63450 Hanau Phone: +49-(0)-6181-309-275 fax: +49-(0)-6181-309-280 info@roevac.com http://www.roevac.com/ Vacuum sanitary systems in Europe, China, VAE, ….
	EVAC 900 	▪ wall or floor mounted ▪ pneumatic operation ▪ sanitary porcelain ▪ 1,2 l per flush ▪ x EUR	**EVAC GmbH** Hafenstrasse 32a D-22880 Wedel Germany Telephone: +49 4103 91680 Fax: +49 4103 916890 info@evac.de http://www.evacgroup.com/update/build70/mr_main.php Vacuum sanitary system for aircrafts, trains, ships, only components supplier, no system calculation.
	EVAC 90 squatting plate 	▪ 1,5 l to 2,5 l per flush adjustable ▪ stainless steel ▪ 1600 EUR	**EVAC GmbH** Hafenstrasse 32a D-22880 Wedel Germany Telephone: +49 4103 91680 Fax: +49 4103 916890 info@evac.de http://www.evacgroup.com/update/build70/mr_main.php
	EVAC 90 kandre 	▪ shock and vibration proof ▪ navy/military design ▪ 1,2l per flush ▪ x EUR	**EVAC GmbH** Hafenstrasse 32a D-22880 Wedel Germany Telephone: +49 4103 91680 Fax: +49 4103 916890 info@evac.de http://www.evacgroup.com/update/build70/mr_main.php

Components		Features	Manufacturer/Contact
Vacuum compact stations	ROEDIGER Vacuum station 	▪ PE 30 to PE 70 plastic vessel ▪ Type 85 to type 360 steel vessel ▪ 650l to 3000l ▪ 80m³/h to 375 m³/h ▪ including control panel, 2 vacuum and 2 sewage discharge pumps ▪ from 20'000 EUR	**ROEDIGER VAKUUM HAUSTECHNIK GmbH** Kinzigheimer Weg 104-106 D-63450 Hanau Phone: +49-(0)-6181-309-275 fax: +49-(0)-6181-309-280 info@roevac.com http://www.roevac.com/
	ROEDIGER Type 140 	▪ steel vessel ▪ 1700 ltr. ▪ 250 m³/h ▪ 2 vacuum pumps 3,0 KW ▪ 2 sewage pumps 7,5 KW	**ROEDIGER VAKUUM HAUSTECHNIK GmbH** Kinzigheimer Weg 104-106 D-63450 Hanau Phone: +49-(0)-6181-309-275 Fax: +49-(0)-6181-309-280 info@roevac.com http://www.roevac.com/
Vacuum units	JETS 15M 	▪ creates vacuum, macerates sewage, pumps sewage ▪ VOD system ▪ available as 15M up to 195MBA ▪ X EUR	**JETS Vacuum AS** P.O. Box 14, N-6069 Hareid, Norway Phone: + 47 70 03 91 00 Fax: + 47 70 03 91 01 post@jets.no www.jets.no
equipment	JETS collection equipment 	▪ Sewage discharged to collection tank ▪ X EUR	**JETS Vacuum AS** P.O. Box 14, N-6069 Hareid, Norway Phone: + 47 70 03 91 00 Fax: + 47 70 03 91 01 post@jets.no www.jets.no
	JETS composting equipment 	▪ Sewage discharged to composting tank ▪ For cottages ▪ X EUR	**JETS Vacuum AS** P.O. Box 14, N-6069 Hareid, Norway Phone: + 47 70 03 91 00 Fax: + 47 70 03 91 01 post@jets.no www.jets.no
	JETS equipment without tank 	▪ Sewage discharged directly to public sewage network (without storage) ▪ X EUR	**JETS Vacuum AS** P.O. Box 14, N-6069 Hareid, Norway Phone: + 47 70 03 91 00 Fax: + 47 70 03 91 01 post@jets.no www.jets.no

	Components	Features	Manufacturer/Contact
Vacuum interfaces	ROEDIGER AE 25  	▪ interface unit for sinks, wash basins, urinals, showers and bathtubs ▪ max. 2 wash basins connectable ▪ pneumatic sensor, controller unit and valve including! ▪ smallest available interface unit! ▪ 300 EUR	**ROEDIGER VAKUUM HAUSTECHNIK GmbH** Kinzigheimer Weg 104-106 D-63450 Hanau Phone: +49-(0)-6181-309-275 fax: +49-(0)-6181-309-280 info@roevac.com http://www.roevac.com/
	ROEDIGER BAG 	▪ make connection of run-offs possible ▪ plastic or steel made ▪ X EUR	**ROEDIGER VAKUUM HAUSTECHNIK GmbH** Kinzigheimer Weg 104-106 D-63450 Hanau Phone: +49-(0)-6181-309-275 fax: +49-(0)-6181-309-280 info@roevac.com http://www.roevac.com/
	▪ ROEDIGER e.g. connection of wash basin and dishwasher to a vacuum system ▪ from left to right: pneumatic sensor, aeration valve, control unit, membrane valve (all including 800 EUR ?) 		**ROEDIGER VAKUUM HAUSTECHNIK GmbH** Kinzigheimer Weg 104-106 D-63450 Hanau Phone: +49-(0)-6181-309-275 fax: +49-(0)-6181-309-280 info@roevac.com http://www.roevac.com/
	JETS Greywater interface 	▪ 16l ▪ use on ships ▪ ventilation desired ▪ steel ▪ X EUR	**JETS Vacuum AS** P.O. Box 14, N-6069 Hareid, Norway Phone: + 47 70 03 91 00 Fax: + 47 70 03 91 01 post@jets.no www.jets.no

Components		Features	Manufacturer/Contact
equipment	JETS collection equipment 	▪ Sewage discharged to collection tank ▪ X EUR	**JETS Vacuum AS** P.O. Box 14, N-6069 Hareid, Norway Phone: + 47 70 03 91 00 Fax: + 47 70 03 91 01 post@jets.no www.jets.no
	JETS composting equipment 	▪ Sewage discharged to composting tank ▪ For cottages ▪ X EUR	**JETS Vacuum AS** P.O. Box 14, N-6069 Hareid, Norway Phone: + 47 70 03 91 00 Fax: + 47 70 03 91 01 post@jets.no www.jets.no
	JETS equipment without tank 	▪ Sewage discharged directly to public sewage network (without storage) ▪ X EUR	**JETS Vacuum AS** P.O. Box 14, N-6069 Hareid, Norway Phone: + 47 70 03 91 00 Fax: + 47 70 03 91 01 post@jets.no www.jets.no
equipment	AIRVAC sewer system technology 	▪ Vacuum valves ▪ Vacuum pits ▪ Vacuum station ▪ X EUR	**AIRVAC** 200 Tower Drive, Unit A Oldsmar, FL 34677 Phone: (813) 855-6297 Fax: (813) 855-9093 seana@airvac.com, davee@airvac.com www.airvac.com vacuum sewerage in U.S., large company
equipment	 Vacuum sewage system	1. Interface unit 2. Gravity 3. Vacuum 4. Piping 5. Vacuum station 6. Biofilter 7. Rising main to sewage treatment plant ▪ X EUR	**QUA-VAC B.V** Televisieweg 157, 1322 BH ALMERE, the Netherlands Phone : +31-(0)-36 54 61 999 Fax : +31-(0)-36 53 50 909 info@quavac.com www.quavac.com vacuum systems supplier for land and ship applications
Equipment	Iseki vacuum systems	▪ Vacuum chambers ▪ Vacuum sewers ▪ Vacuum stations ▪ X EUR	**Iseki Vacuum systems Ltd.** High March DAVENTRY Northamptonshire, NN11 4 QE Phone: +44-(0)-1327-878777 Fax: +44-(0)-1327-315232 sales@iseki-vacuum.com www.iseki-vacuum.com