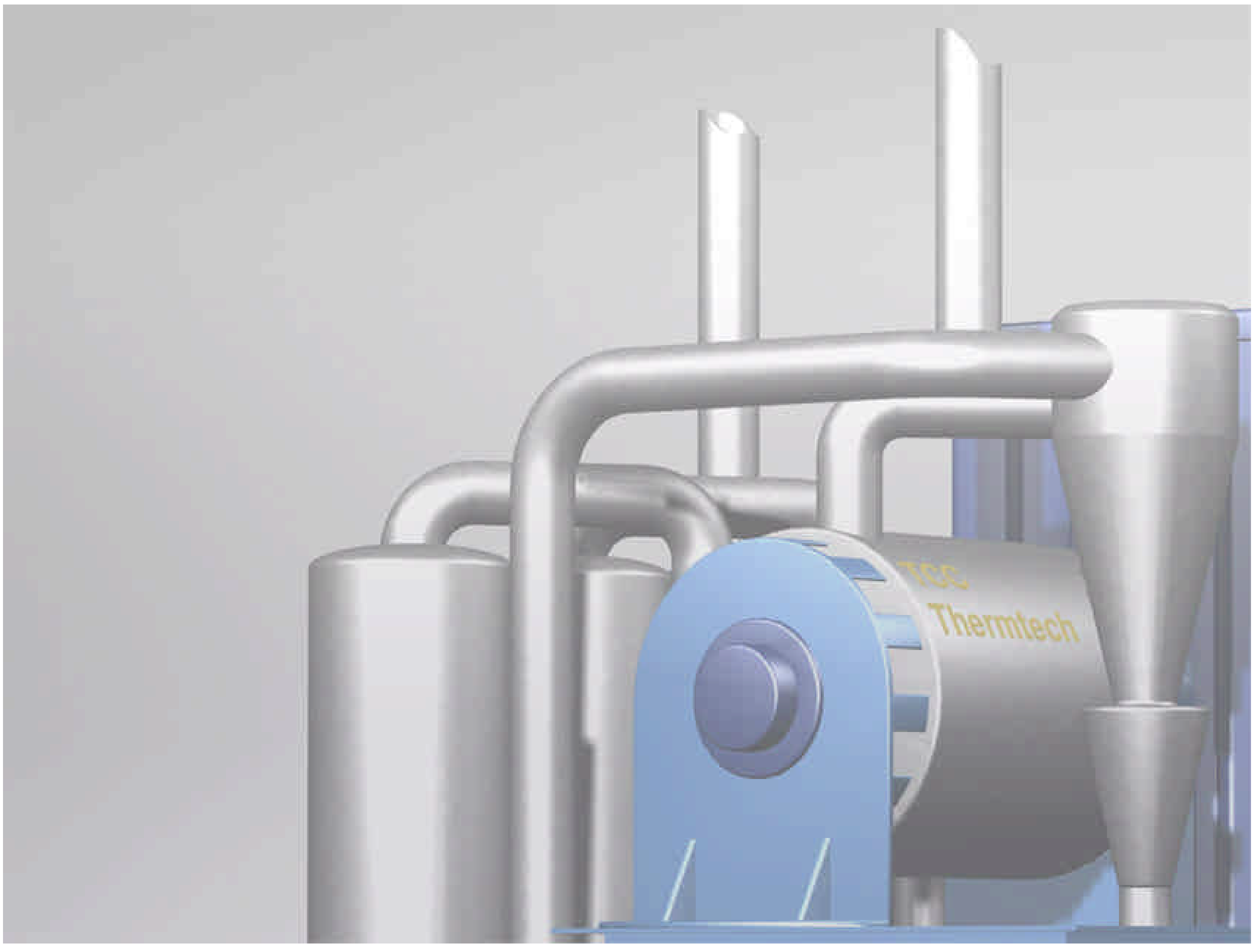
Technology Presentation



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TCCâ - Thermomechanical Desorption Process for Drilling Waste

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Solving the Problem of Treating Drilling Waste

Why thermal desorption?

Offshore discharge of oil based drilling waste (drill cuttings and used drilling fluids) is generally not acceptable because of the environmental impacts. Transport onshore for treatment and/or disposal is for a large fraction of the drilling operations the only appropriate solution. Thermal desorption implies adding heat to a material resulting in a temperature rise above the vaporisation point of the volatile compounds in the material. By subsidiary cooling of the vapours the volatile compounds can be recovered and fractionated. In oil based drilling waste the main volatile compounds are the base oils and the water from the drilling mud. For separation of drilling waste into reusable base oil, and in the same process reach a residual oil level in the solids that meets common standards for disposal or alternative use, thermal desorption has proven to be both environmentally and commercially accountable.

Oil, water and solids in drilling waste

Drilling waste from drilling operations utilising oil-based mud consists of the three major substances: Water, oil and rock/clay. The typical solids content is 70-85%wt, and the fluid fraction normally contains more oil than water (2/1). The fines (barite and bentonite) are components in the drilling mud and the rock is the cuttings from the drilled hole. The mud oils are specially refined low toxic oils with certain properties. Distillation curves for commonly used mud oils show typical recovery in the temperature interval 200-350°C at ambient pressure. Capillary forces efficiently resist the transport of oil to the surface of the solid particles. As a result of this it is required to heat the material to temperatures well above the vaporisation point of the oil in order to achieve the required vaporisation rates and complete removal of oil from the solids. This can be compensated by longer retention times in the thermal unit, but both higher temperatures and longer retention times induce thermal degradation of the base oil. In the next phase this will obstruct reuse of the recovered oil in drilling fluids, and thereby significantly reduce the added value in the operation.

Benefits with TCC thermomechanical desorption

The TCC thermomechanical desorption process has some obvious technical advantages compared to traditional thermal desorption systems. The process is based on direct mechanical heating, which eliminates the need for large heating surfaces and complex systems for heating of some heating medium like hot oil, steam or exhaust gas. Engines, turbines or electric motors are applicable for generation of mechanical energy, and this makes it is possible to design systems that are both compact and meet the highest relevant safety and explosion proofing standards.

The major benefits with TCC thermomechanical desorption from a physiochemical point of view are the limited process temperature and the very short retention time required for complete removal of oil in the solids. This significantly reduces the risk for thermal degradation of the valuable mud oils. Based on GC/MS fingerprint scans there exist no obstacles for reuse of the recovered TCC oil in new drilling mud. This becomes possible due to the special mechanism for heat generation in the process.

In the TCC thermomechanical desorption process heat is produced internally in the material by friction forces generated by intense agitation. The combination of high mechanical shear and in-situ heat generation creates an environment that promotes flash evaporation of water and hydrocarbons. This is a result of an extremely efficient turbulent mixing that reduces the thickness of the laminar oil vapour layer surrounding the oily particles. In the turbulent bulk gas phase outside the laminar layer super heated water vapour is the dominant component on volume basis, due to the large difference in molar mass between the oils and water. The partial pressure of water vapour is above 75% for a typical drilling waste as specified above. This promotes an efficient steam distillation of the oils, which makes it possible to vaporise oils at a temperature well below their atmospheric vaporisation point, thereby eliminating the risk for thermal degradation.

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Another benefit with the process is that the intense agitation efficiently breaks up the solid particles giving minimal diffusion distances for oils that are bounded internally in particles by capillary forces. This reduces the required retention time in the process unit for complete removal of oil in solid. The latter increases the tolerance for heavy organic species in the waste because the extremely short retention time makes it possible to increase the process temperature from that required for full vaporisation of oil, without inducing thermal degradation of the oil.

From an environmental viewpoint, the advantage of the TCC thermomechanical desorption process is the high degree of recovery of the substances for reuse. Operators of the TCC thermomecanical desorption process are able to recover the base oil for reuse in new drilling mud, and the solid particles have a quality that makes it valuable as a filler material in different industrial products. This is a key element when considering what is the best available technique (BAT) pursuant to Council Directive 96/61/EC on Integrated Pollution and Prevention Control (the IPPC Directive). The TCC desorption process is considered to be BAT by an increasing number of the relevant market players.

Issues related to mud-chemicals

Various chemicals are mixed into the drilling mud to create the required properties. Several of these are organic compounds like surfactants used as emulsifiers and wettability control agents, asphalt for viscosity or filtration control and polymers for filtration control. For thermal desorption processes such chemicals represent a problem because of their highly variable thermal stability. Some chemicals may be fully thermally decomposed to harmless components, whereas others are partly degraded to unwanted by-products found in recovered solids, oil and water, depending on the physiochemical nature. The result is a certain level of residual organic matter in the recovered solids and a need of further cleaning of the recovered oil in order to reuse this for new mud. Moreover, some sort of cleaning of the recovered water may also be necessary depending on the options for disposal of this effluent.

Alternative processes

Established alternatives for the TCC thermomechanical desorber are the drum type processors and the hot oil processors. Some of these are based on old and well-proven techniques for dehydration of sludge and bulk materials, and have also become widely used within the field of drilling waste treatment. The subsequent process solution for recovery of the vaporised components and the hot dehydrated solids can be significantly different from supplier to supplier, but all process solutions have the objective of recovering clean oil, water and a solid phase suitable for the intended use or disposal.

Indirectly heated processors of the drum type utilise hot exhaust gas from combustion of a suitable fuel to heat the material. The processors are typically constructed with a rotating drum placed inside a jacket. The material is agitated and transported through the processor inside the rotating drum, while heat is supplied through the wall of the drum from the hot exhaust gas that flows between the jacket and the drum. The axial transport of the material bed is controlled by the inclination angle of the drum. In order to avoid the formation of an isolating layer of dried soil or clay on the inside of the drum, it is necessary to re-circulate treated solids. The overall heat transfer from the exhaust to the material is low, and this induces relatively large heating surfaces and correspondingly large and capital demanding process units. The units have the ability to heat the material to very high temperatures (>500°C), which gives efficient removal of oil from the material, but with high probability of thermal degradation and thermally decomposed residuals in the recovered solids. The retention time of the material in the processors is typically in the range of 30 – 150 minutes, again increasing probability of cracking.

Hot oil processors represent another principle for indirect thermal desorbers. The heat is transported to the material by means of hot oil circulating inside hollow rotors designed with a large heating surface. The rotor also acts as agitator and creates the required axial transport in the material bed. The primary heat source for the hot oil is conventional fuels. Large heating surfaces are required due to a relatively low heat transfer coefficient between the hot oil and the bulk material inside the processor, and the fact that commercial hot oils have a maximum operating temperature not so far from the required process temperature. The latter limits the usable temperature difference for the heat transfer. Some units utilise electric heating on parts of the heat surface to be able to reach the temperatures required for complete removal of oil in the material. Long retention times in the range of 30-150 minutes are also required for complete removal of oils, again high cracking probability exists.

There are alternatives to thermal desorption for treatment of drilling waste. The status of some alternatives is briefly:

- Solvent extraction using hexane and centrifuges with subsequent separation of oil, water and hexane by distillation has been used to some extent.
- Solidification/stabilisation has been used to some extent, but excludes reuse of the oil.
- Bio remediation is in use, but has not gained significant importance for drilling waste. The oil is biologically degraded and lost.
- Incineration is well established and leaves a very clean solid phase. Also this method excludes reuse of the oil and generates more gaseous emissions than the other processes.

Description of the TCC Process

How does it work?

In the TCC process heat is produced through dissipation of the mechanical energy supplied to the material bed from the rotor as shown in Figure 1. The material bed is kept fluidised in a well mixed bed near the walls of the stator by a combination of flash vaporisation of fluids and the centrifugal force field generated by the highly turbulently rotating material. The overall dimension of a normal reactor is about 1×1 m (internal length × internal diameter). The total bed mass is limited to 200-400 kg of solids. This corresponds to an average retention time for solids in the reactor of 6-12 minutes, but only 15-30 seconds for the oil.

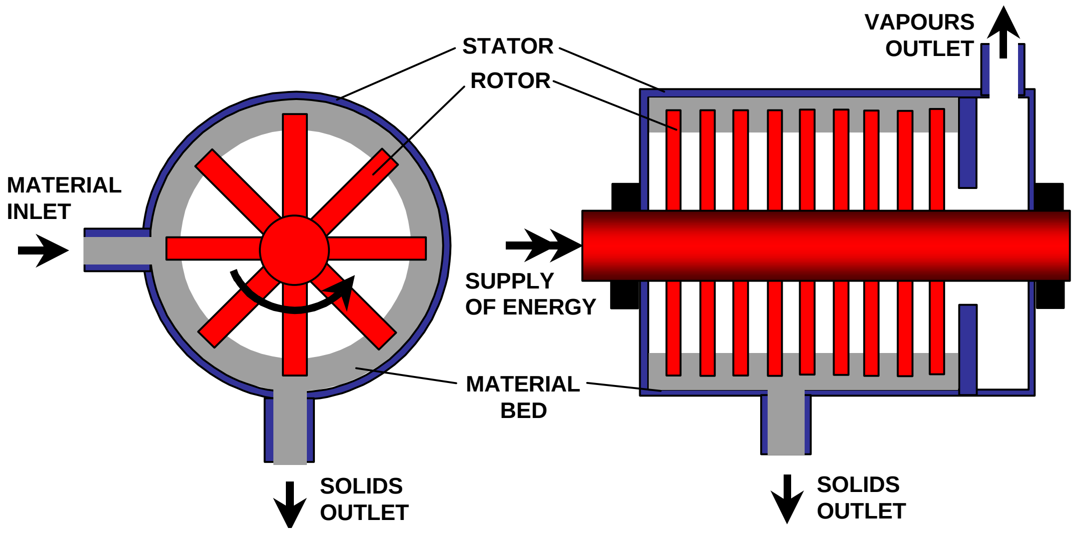

Figure 1 Principal figure of the TCC process mill.

Flow sheet for the TCC process

A simplified flow sheet of a TCC process is presented in Figure 2. The drilling waste must be screened for larger objects that might damage the equipment. This is done by means of a vibrating screen on top of the feed hopper. For smooth and

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stable feed of material to the TCC process chamber double piston pumps based on the principle of *concrete pumps* have proven to be the most reliable solution. The process chamber itself is principally described in Figure 1. Due to the compact design and efficient crushing of solids significant amounts of ultra fine particles follow the vapours out of the process chamber. These are efficiently removed by means of a cyclone separator and a special dust separator before the condensers. Recovered solids are discharged through cell-valves and transported away from the process unit by means of conveyors. Oil and water are recovered in a multi step condenser arrangement. Seawater, cooling towers or radiators may be used for cooling of the condenser arrangement.

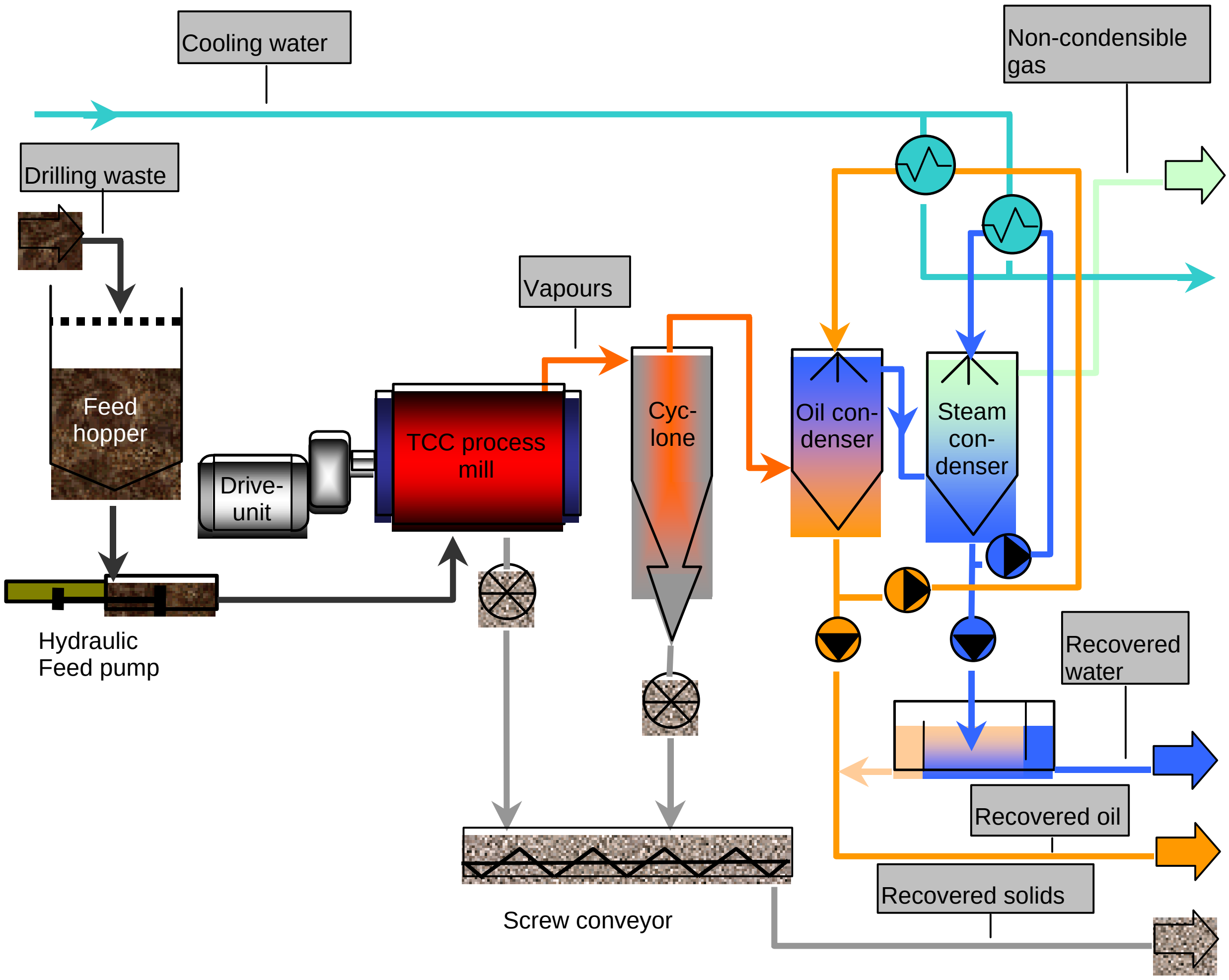

Figure 2 Process flow sheet for the TCC process.

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Performance, energy consumption and emissions

The mechanical work supplied through the drive shaft is the only energy put into the thermal desorption process. The required energy input for a continuously operating steady state TCC process is then described by the familiar first law of thermodynamics for a steady state and steady flow control volume:

$$\dot{Q}_{C.V.} + \Sigma\, \dot{m}_i \,(h_i + \mathbf{V}_i^2 + gZ_i) = \Sigma\, \dot{m}_e \,(h_e + \mathbf{V}_e^2 + gZ_e) + \dot{W}_{C.V.}$$

The convenient control volume to consider is the process mill alone with its inlets and exits. Assuming no significant chemical reactions and neglecting the changes in kinetic and potential energy, the first law takes the form:

$$P_{Shaft} = \dot{m}_{Solids}\,\Delta h_{Solids} + \dot{m}_{HC}\,\Delta h_{HC} + \dot{m}_{H2O}\,\Delta h_{H2O} + Q_{Loss}$$

Where P_{Shaft} is the power supplied through the shaft and Q_{Loss} is all heat lost from the process mill. Typical drilled cuttings have a fluid content of 15% to 30% by weight. The fluid consists of about 2/3 oil and 1/3 water in average. Some examples of first law balances for the thermomechanical desorption process of drilling waste are presented in Table 1. A feed material temperature of T_i = 20°C and a typical process temperature of T_e = 300°C are used. The specific heats for solids and oil are based on common values for clay/limestone and diesel oil. This gives good overall agreement for typical drilling waste.

Table 1 Energy balance for treatment of 1 ton per hour of drilling waste of different composition.

Composition Solids/Oil/Water (%wt):	85/10/5	77.5/15/7.5	70/20/10	70/15/15	50/25/25
Enthalpy change for solids (kW)	85	53	48	48	34
Enthalpy change for oil (kW)	24	36	48	36	60
Enthalpy change for water (kW)	41	62	83	124	207
Heat loss (kW)	7	7	7	7	7
Required power supply (kW)	131	158	186	215	308

As can be found from Table 1, the expected capacity for an electric powered TCC installation of 450 kW on average drilled cuttings with 77.5% solids by weight is about 2.8 tons per hour, assuming a loss of 5% between electricity supply and TCC drive shaft. The capacity is reduced when wet materials in the form of used drilling fluids are mixed with the cuttings. For a more viscous mixture of drilling waste of 70% solids, 15% oil and 15% water the capacity is reduced to 2.0 tons per hour, which is a typical throughput in the TCC installations in operation today. The required input of mechanical work is independent of the type of drive system. Table 2 compares some alternatives, for which fuel consumption and CO_2 emissions are presented for comparison. The tabulated values are only valid for the assumed total efficiency and fuel quality.

Table 2 Fuel consumption for a capacity of 1 ton per hour with different drive systems on the TCC.

Drive system	*Total efficiency*	*Heating value*	*Consumption*	*CO_2 emission*
Electric	95%		166 kWh	0
Diesel engine	35%	42 MJ/kg	44 litres/hour	120 kg/hour
Natural gas engine	35%	49 MJ/kg[a]	42 Sm^3/hour	113 kg/hour
Natural gas turbine	20%	49 MJ/kg	73 Sm^3/hour	196 kg/hour
Steam turbine	70%	0.307 MJ/kg[b]	2647 kg/hour	56 kg/hour[c]

[a]Natural gas with 93% CH_4 is used in the table.

[b]"Heating value" corresponds to enthalpy change for steam between 20 bar superheated and 5 bar saturated.

[c]From the additional fuel gas required for bringing the steam to 20 bar superheated instead of 5 bar saturated.

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Quality of treated products

As pointed out in an earlier section, the major benefits with TCC thermomechanical desorption from a physiochemical point of view are the limited process temperature and the very short retention time required for complete removal of oil in the solids. As a result of this, the TCC units in operation today are able to recover solids with a residual oil level in the range 100-1000 ppm. The short retention time also significantly reduces the risk for thermal degradation of the valuable mud base oils. Based on GC/MS fingerprint scans there exists no obstacles for reuse of the recovered TCC oil in new drilling mud. With the special dust separator installed the recovered oil typically contains <0.1% ultra fine clay particles. After removal of residual free oil, the quality of the recovered water allows direct discharge to sea or available wastewater treatment facilities at most locations (< 15 ppm oil). There will always be a certain content of residual organic species originating from the various chemicals in the drilling fluids. Different analyses show TOC levels in the range 1000 – 3000 ppm. Further waste water treatment may be required in case of very strict requirements for effluent discharge.

Operator requirements

TCC units are designed for continuous and automatic operation, and the man-hour requirements with the process are low. No permanent presence in control room is required however one operator must be present at the plant during operation of the TCC in case of any disturbances/alarms. Bringing the drilling waste to the feed system and replacing solids containers at the outlet must normally be done manually, so the total man-hour requirement depends strongly on how these interfaces are arranged. TNW will provide a large buffer tank for feed, which will store enough cuttings for approximately up to 6 hours of operation. During this period the manual work is limited to replacing dry solids containers.

Safety Aspects

TCC units are designed and supplied with high priority to intrinsic safety. A highly qualified institute, GexCon a part of the CMR group, has carefully evaluated the explosion and fire hazards of a complete TCC installation. New installations are designed as suggested in this study, which implies full compliance with:
Directive 94/9/ECC of the European Parliament and the Council of 23 March 1994 on the approximation of the laws of the Member States concerning equipment

Protective systems intended for use in potentially explosive atmospheres, Official Journal of the European Communities No. L100/1, 19 April 1994

In addition to this, a TCC unit is designed to comply with the Machine Directive (Directive 89/392/EEC), which implies that other relevant hazards are taken care of as required.

As part of the above-mentioned study a zone classification around the TCC installation has been performed in accordance with relevant parts of:

International Electrical Commission (1995) Electrical apparatus for explosive gas atmospheres. Part 10: Classification of hazardous areas, IEC 79-10, Third edition 1995-12
British Gas Transco, Procedures for Hazardous Area Classification of Natural Gas Installations, Draft 1988

According to the study a TCC installation will create a zone 2 in a distance of:

0,25m from all vessels and pipelines containing heated drilling waste.
1,1 m from all sample points

The above is valid as long as the equipment is placed inside a building with permanent openings allowing natural ventilation and for a minimum flashpoint of the base oil in the drilling waste of 65°C.

Technical Description of a TCC Plant

General dimensions and layout

A standard 450 kW TCC, electrical driven, unit consists of the following main modules with total overall dimensions indicated (Length×Width×Height):

- Feed hopper and feed pump 3500×1700×3000 mm
- Process mill and drive unit 6000×2500×4500 mm
- Condenser package 6000×2500×4500 mm
- Cooling tower (optional) 1800×1800×4500 mm
- Control room (10' container) 3000×2500×2500 mm

The TCC plant layout is flexible. A principal layout is indicated in Figures 6 to 8 (Control room and cooling tower are not shown, as they can be located outside the processing area). Alternative layout may be chosen if required.

Suggested production facilities:
Required building size for TCC unit only is 250m². A rigid concrete floor for the main modules is needed.
Basin size for drill cuttings must be in accordance with the expected batch sizes delivered. On a site with a 450kW unit is the typical basin size 1000 metric tons.
Cranes for internal transport of cuttings between basins and TCC unit is required.
Tank capacity for recovered oil must be at least 150m3 based on oil transports every week.
Recovered water treatment facilities must be available. Preferably the recovered water is pumped to a wastewater treatment plant if available.
Dry solids containers storage area must be available.
Cleaning and storage area for cuttings containers must be available.

Utilities requirements

- Power or fuel consumption for drive system: 450 kW for electric motor
  125 litres/hour for diesel engine
  120 Sm^3/hour for natural gas engine
- Power consumption of auxiliary equipment: ~50 kW
- Electrical power: 3×400V, minimum 1200kVA. 220V for control system
- Compressed air: Dry air at 8 bars.
- Municipal water: Fresh water for filling of cooling circuits
- Nitrogen supply: Ca. 8 m3 per each start up and shut-down

Control system and man-hour requirements

The TCC process is 100% automatically controlled with a comprehensive alarm system. The TCC is normally supplied with a PC based HMI system in the control room. On the PC the operator can watch all process parameters, change set points, handle alarms and prints out logs. Constant surveillance of the process is therefore not required as long as personnel are on-site and available in case of alarms.

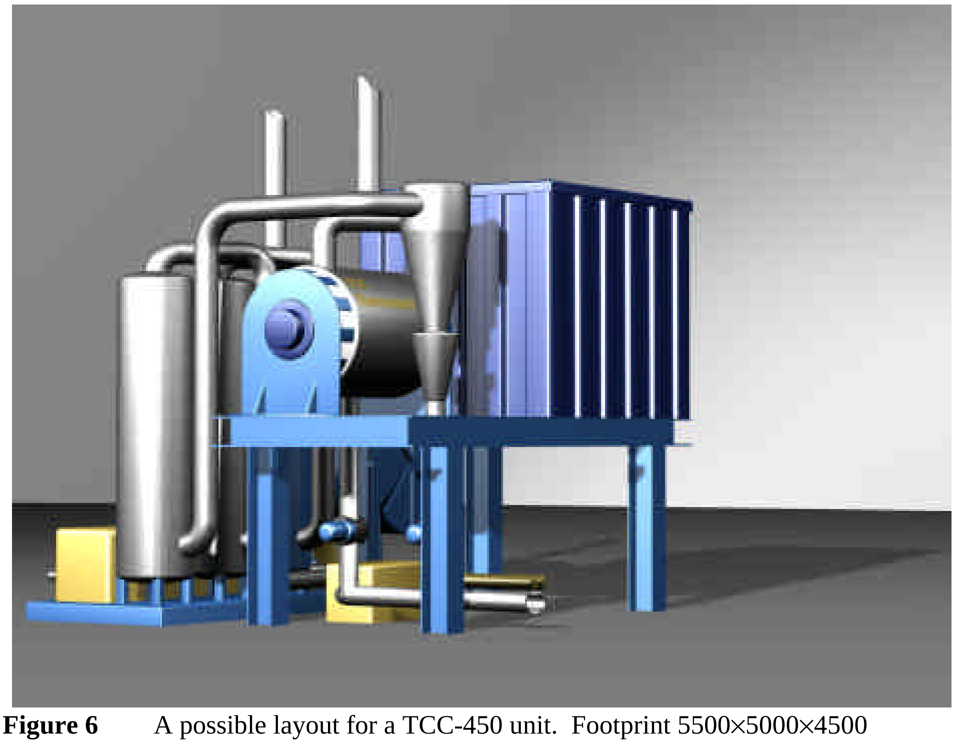

Figure 6 A possible layout for a TCC-450 unit. Footprint 5500×5000×4500

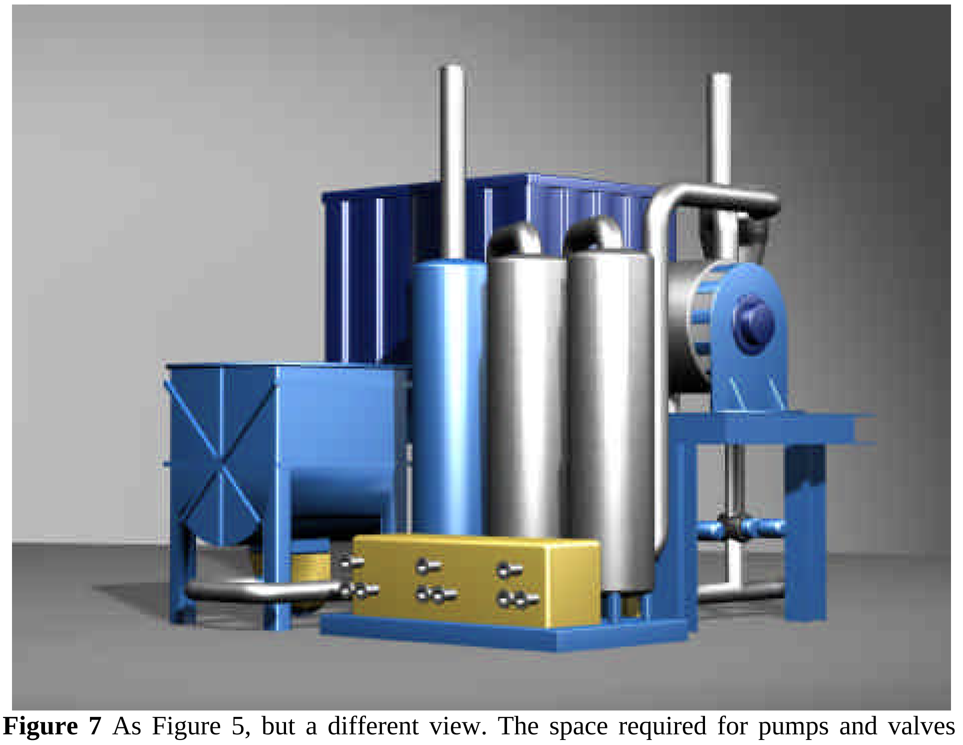

Figure 7 As Figure 5, but a different view. The space required for pumps and valves etc. on the condenser package is shown as a rectangular box for simplicity. The flanges indicate the required pipe connections for coolers and discharge of effluents.

Figure 8 As Figure 5 and 6, but a view that shows the feed hopper with the feed pump underneath.

Safety issues and site requirements

Highly qualified experts within this field have carefully assessed the risk for explosions and fire. It is concluded that the process plant with its protective measures complies to the Essential Health and Safety Requirements laid down in directive 94/9/EC (ATEX directive) concerning equipment for use in potentially explosive atmospheres. A zone classification has also been performed, and with natural ventilation or a normal level of forced ventilation in the production hall the process plant produces the following zones:
Zone 2 in a distance of 0,25 m from all insulated parts of the plant.
Zone 2 in a distance of 1,1 m from the sampling points.

Auxiliary processes and equipment

Depending local conditions and specific customer requirements auxiliary processes and equipment may be implemented in addition to the basic TCC process. For the following purposes TNW has experience with various solutions, and for each project we will be able to propose an optimum solution for the customer:

- Feed supply system
- Solids discharge/handling system
- Cooling of process effluents
- Pipelines and storage tanks for recovered fluids
- Recovered oil polishing
- Recovered water treatment
- Non-condensed gas treatment

Flexibility and system design

Due to its compact design and modular configuration there exist various options for adoption of the TCC process to meet the specific requirements for different potential customers of the technology:

- Fixed installations integrated in a larger processing plant environment.
- Multiple units for increased treatment capacity and availability.
- Mobile units for rapid mobilisation close to the waste source.
- Compact and fully Ex. proofed units for operation in demanding environments (e.g. offshore oilrigs and refineries).

Maintenance requirements

As a result of the intense agitation inside the process mill, it is necessary to regularly renew the abrasion resistant material inside the process mill. This will have to be done between each 3000-6000 hours of operation, depending on the process conditions. An efficient solution for this is to switch between two complete sets of process mills, so that one mill can be renewed while the other is in operation. The switch itself can be accomplished during a 2-3 days maintenance shut down, which also allows all other major parts of the plant to be checked and overhauled as required. Using this strategy an availability of the TCC of up to 95% is possible.

Reference Installations

TCC-450 kW installation operated by Soilcare AS

- Location of plant: Mongstad, Norway
- In operation since: September 1998
- Drive system: Electric motor 450 kW
- Type of feed: Various types of drilling waste from Norwegian drilling activities
- Typical through put: 1,5 – 2,5 tons per hour due to highly variable water content
- Operation time: 8000 hours per year
- Use of recovered oil: Re-circulated for new drilling fluids or sold as fuel oil
- Use of recovered solids: Used in asphalt production
- Recovered water: Discharged to sea

The reference installation is shown in Figure 3.

Figure 3 The TCC-450 kW installation operated by Soilcare AS.

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CC-450 kW installation at North Refinery

• Location of plant:	The Netherlands
• In operation since:	Planed start up May 2003
• Drive system:	Electric motor 450 kW
• Type of feed:	Various types of drilling waste
• Typical through put:	1,5 – 2,5 tons per hour due to highly variable water content

Figure 4 The TCC-450 kW in operation at North Refinery.

Other installations

In addition to the above, two TCC installations have been supplied to Total Waste Management Alliance Plc., U.K., formerly Burgess & Garrick Oil Services Ltd.

- TCC-132 kW with electric motor.
- TCC-515 kW with diesel engine.

Figure 5 A diesel powered TCC installation.