Total Oil Remediation and Recovery (TORR™) Remediate Hydrocarbon Contaminated Water – No Additional Waste Created

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Abstract: Hydrocarbon contamination of groundwater is a serious environmental problem and presents many challenges when a treatment process needs to be designed to remediate hydrocarbons and other contaminants. EARTH (Canada) Corporation has developed a revolutionary technology that separates free-floating and emulsified hydrocarbons from water. The technology – TORR™ (Total Oil Remediation and Recovery) separates the hydrocarbon contaminants, which can then be reused or recycled. No waste is created and no additional heat or chemicals are required. The treated water can then be sent to other membrane technologies for further treatment of heavy metals and other aqueous pollutants.

The TORR™ technology principles will be explained along with actual case histories to further exemplify the benefits of this technology when tackling groundwater issues and where possible cost reductions can be realized. Other examples of remediation will be highlighted.

Introduction: Oil and grease are present at numerous commercial, industrial and government sites. The presence of oil poses a severe challenge for oily water remediation technologies. Oil and grease must generally be removed from wastewater since those materials can foul instruments and equipment, interfere with other processes and may accumulate in unwanted areas causing a hazard or performance problem. Furthermore, oil and grease are very damaging to the environment and could cause a significant pollution problem.

Oily wastewaters are produced in petroleum production, refining, storage, petrochemical complexes, steel and metal industries, textile and food industries. Oil spills and contaminated groundwaters are also large generators of oily waters. The resulting effluents vary widely in volume and in oil content and thus the treatment requirements must be based on the oily water's unique characteristics and its ultimate end use.

Basic Separation Theory: The removal of oil and grease from wastewaters can be accomplished by the use of several well-known and widely accepted techniques. However, the performance of any given separation technique will depend entirely on the condition of the oil-water mixture. Present techniques for the separation of oil from water are based on their difference of density. Stoke's Law states that rising velocity (V_r) is a function of the square of the oil droplets' diameter.

$$\text{Stokes Law } V_r = g\, d^2 (\rho_w - \rho_o) / 18\, \eta$$

Where

V_r	= rise velocity of oil droplet
g	= acceleration due to gravity
ρ_w	= density of water
ρ_o	= density of oil
d	= oil particle diameter
η	= viscosity of water

From Stoke's Law, it can be seen that droplet size has the largest impact on rising velocity rate. Consequently the bigger the droplet size, the less time it takes for the droplet to rise to a collection surface and thus the easier it is to treat the water. The oil in the wastewater can be present as free-oil, and/or emulsified, and/or dissolved states in different proportions. This oil droplet size distribution is the most important factor affecting the design and selection of oil-water separators for a given application.

Free-oil is defined as an oil droplet of 150 microns which will float immediately to the surface due to its large size and high rise velocity. Emulsion is oil which is dispersed in the water in a stable fashion due to its small diameter and its low rise velocity.

Emulsions can be found in two types: mechanical emulsions and chemical emulsions. Mechanical emulsions are created through the process of pumping, large pressure drops through chokes, control valves, and otherwise mixing the oil-water solution. Chemical emulsions are sometimes intentionally formed using chemicals to stabilize the emulsions for an industrial process need or other use.

Gravity separation is the mechanism most commonly used for the removal of oil from wastewaters. This process primarily affects free oil. Tight oil emulsions and dissolved oil will not be removed by gravity separation alone. The objective in treatment of wastewater containing emulsified oils is to destabilize the emulsion so that the oil will separate by gravity or flotation. Essentially what is done is to promote inter-droplet contact with the purpose of developing larger droplets that will be easier to remove. Once the emulsion is broken, the same removal techniques applicable to free oil can be utilized. Small oil droplets are always difficult to separate. The smaller the droplets, the lower their rising velocity will be. A prerequisite for efficient separation is, therefore, that oil droplets coalesce (become larger and rise more rapidly).

A large number of simple gravity oil separation devices are available, varying from API (American Petroleum Institute) separators to Parallel Plate Interceptor (PPI) and Corrugated Plate Interceptor (CPI). The API gravity separator removes oil globules of 150 microns or greater where PPI and CPI separators can remove oil droplets down to 30 microns.

The second common method of oil and grease removal is through induced (IAF) or dissolved (DAF) air flotation (other gases such as methane, carbon dioxide or nitrogen can be used instead of air in some applications). Air is introduced (either at atmospheric pressure or dissolved under pressure) to provide air bubbles, which tend to attach to the oil droplets decreasing its specific gravity and then float quickly to the surface. More rapid oil removal can be achieved than by gravity alone, resulting in smaller footprint. Finally, it is often necessary to use chemical coagulants with flotation units. Chemicals such as demulsifiers, alum, ferric chloride and cationic polyelectrolytes are used to improve the efficiency of oil and grease removal.

Another factor that affects the rise velocity of an oil droplet is the acceleration force (see Stoke's Law). Hydrocyclone performances are mainly governed by the centrifugal (g-force) applied to a spherical droplet in a centrifugal separation field. A liquid-liquid hydrocyclone separates free and dispersed oil from wastewaters with an applied centrifugal force many orders of magnitude greater than gravity (usually between 2000 to 3000 g). Centrifugal force causes the heavier water phase to migrate to the vessel wall while the lighter oil phase forms a central, low-pressure core from where it is recovered. Treatment chemicals may enhance hydrocyclone performance by facilitating emulsion breaking and droplet coalescence. Field applications showed that emulsions larger than 15 to 20 microns are removed efficiently by hydrocyclones.

The centrifuge is another enhanced gravity separation process which combines high acceleration forces (5000 to 10,000 g-force) and a large settling area to simultaneously separate dispersed oil down to 3 to 7 microns droplets from oily-waters.

Filtration, another category of the oil separation process, is used but in limited applications due to its high maintenance cost requirements. In filtration, oily water is passed through a porous medium with or without the addition of treatment chemicals.

Applied pressure is used to overcome the flow resistance of the filter medium. Oil is usually retained and removed in the medium. The end of the filtration run is indicated when the filter medium becomes excessively contaminated with oil, at which point the medium must be cleaned or replaced. A single or multi-bed media material can be used as filtration medium. The most commonly used are sand, anthracite, crushed walnut and pecan shells, which can be used as a single-media or a combination of those. All of these materials must be backwashed or replaced when saturated which will create subsequent treatment and disposal problems (frequency of backwashing depends on service but 24 hour cycles are not uncommon). Performances vary widely depending on the type of filter, the operating conditions and the oily water's unique characteristics. The primary advantages and disadvantages of the previous oil separation processes described above are given in Table 1.

The challenge of removing small oil droplets: Even under favorable conditions, oil droplets smaller than about 30 μm in water are known to be quite difficult to separate. Oily water with small droplets < 30 μm may then represent such a high proportion of the oil content that it is impossible to achieve discharge specifications with conventional equipment.

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Principle of EARTH's TORR™ Technology: The TORR™ System (Total Oil Remediation and Recovery System) was developed and implemented by EARTH (Canada) Corporation. This technology designed for oily water treatment (both free and emulsified oils) offers an effective, reliable and economical process. Its performance meets, and more often exceeds the strict regulation requirements all over the world.

The TORR™ System is based on the filtration, coalescence and gravity separation processes. The novelty and the originality of the process lies on the fact that it combines these three principles in one single process and by its special design makes the TORR™ System a self-cleaning oily water filtration system. To achieve this, RPA® (Reusable Petroleum Absorbent), a hydrophobic absorbent developed and patented by EARTH (Canada) Corporation is used as a filtration medium in the TORR™. The RPA® being highly oleophillic, allows the absorption of very fine emulsions down to 2 microns. Another characteristic of the RPA® lies in its capacity to continue to absorb the fine emulsions even when it's fully saturated with oil, while continuing to desorb the coalesced oil as free-floating oil. These two principle characteristics of the RPA® (absorption of fine emulsions and desorbtion of free-floating oil) allows the development of an efficient process (removal of oil emulsions down to 2 microns) and a self-cleaning system (continuous oil separation and recovery). This results in low operation and maintenance costs for the remediation process.

For a higher performance than conventional processes (Oil/Water separators, coalescers, DAF, hydrocyclones, centrifuges etc.), the TORR™ System is more compact (hydraulic rate of 20 $m^3/m^2.h$), fully automated, doesn't require any chemical additives to break the emulsions and isn't affected by load oil flow fluctuations (see Figure 1).
The TORR™ System consists of an engineered envelope divided in several compartments. The highly oleophillic and hydrophobic sorbent, RPA®, is filled in every second consecutive compartment. The other compartments are empty (which act as a small oil/water separator).

The RPA® has the ability to adsorb the free-floating and the emulsified oil on its surface. When it's fully saturated with oil, it releases the extra oil but continues to adsorb the incoming oil. At equilibrium state (when the RPA® is totally saturated), the quantity of oil released is equal to the quantity of oil adsorbed. The oil released is then recovered in the empty compartments.

The absorption/desorbtion process can be accomplished because when the emulsified oil passes through the RPA®, the fine emulsions are adsorbed and transformed into larger droplets which float very easily. The oil droplets are easily separated by gravity in the empty compartments and discharged automatically out of the system. This makes the TORR™ System a self-cleaning process.

The transformation of the oil droplets and the recovery of oil considerably increase the quantity of oily water to be treated. Only the last two compartments of RPA® must be centrifuged or replaced from time to time. (Every 6 to 12 months depending on operating conditions)

Conclusions: TORR™ (Total Oil Remediation and Recovery) technology offers an alternative and new solution to removing emulsions from water. Emulsions 2 microns and larger are coalesced, separated and recovered from water often resulting in treated water hydrocarbon content well below 5 mg/L.

Case History – Fort Smith (NWT) Aurora College Remediation Project: In September of 1996, during a tank replacement program, contractors and staff at the Aurora College in Fort Smith, Northwest Territories excavated a heating oil tank from the Trades Building property. Groundwater entering the excavation was discovered to contain heating oil.

Investigation of the soils and groundwater quality was conducted in 1996, 1998 and 2000. Also in 2000, further testing of soils and groundwater took place in the residential area north of the Trades Building site, including the Raven Crescent, Cassette Crescent and Cassette Place residential areas. It was determined that the heating oil tank had probably been leaking oil over many years, possibly since it was installed in 1972. The studies concluded that most of the liquid heating oil had stayed on the Trades Building property although some had seeped into the Raven Crescent road right-of-way.

The Challenge: The water table required to be lowered in the contaminated area of approximately 7,500 square meters. The existing water table was approximately 4 meters below grade and the contamination in the water table was down to about an additional 7 meters. A preliminary 3-meter pre-cut excavation was performed. At this level, over 700 well point systems and 700 meters of header systems were installed. Once the water table was lowered, the entire area was excavated to below the contamination level and the soil was taken to a specially constructed area to be spread out and land farmed.

The heating oil contaminated groundwater needed treatment before being discharged back into the environment. As with many groundwater contaminated sites, the levels of free-floating and hydrocarbon emulsions can be difficult to measure. The owners and engineers needed an added level of insurance that treatment would be performed in light of the uncertainty of hydrocarbon emulsion levels. Traditional treatment process streams generally involve a pumping system, oil-water separator and activated carbon as the final polishing stage. Although this process meets the treatment requirements, the amount of activated carbon required varies depending on the levels of hydrocarbon contamination. This presents a challenge when determining the overall costs of the groundwater treatment process.

Bill Vriens of Groundwater Control Systems Inc. in Edmonton contacted EARTH (Canada) Corporation's Alberta agent Jason Kropp of Berja Meters. Mr. Kropp suggested EARTH (Canada) Corporation's TORR™ technology as a solution for treating the hydrocarbon contamination. TORR™ (Total Oil Remediation and Removal) incorporates EARTH's RPA® (Reusable Petroleum Absorbent) which acts as an emulsion breaker, coalescing the oil emulsions 2 microns and larger and separating the hydrocarbons from the effluent stream. The recovered hydrocarbons can be reused or recycled. This results in treated water reaching hydrocarbon concentrations of less than 5 ppm (parts per million). The TORR™ technology is a continuous process and capable of treating large volume flow streams without the need for added chemicals or heat. No waste is created from this technology. The TORR™ has a small footprint allowing for easy transportation to site and requires minimal operational involvement and energy requirements.

The proposed treatment stream involved traditional pumping systems, settling tanks, solids prefiltration equipment and the TORR™ system. An air stripper was installed to address the treatment of BTEX's. What was eliminated from the treatment stream was the need for activated carbon. TORR™ enabled more accurate cost projections and opportunities for cost reductions due to the elimination of landfill costs, additional carbon purchase and replacement.

The TORR™ system treated over 20,000 cubic meters of hydrocarbon-contaminated groundwater. The results of the treated groundwater were TPH (Total Petroleum Hydrocarbon) concentrations well below 5 ppm and often concentrations were non detectable. The TORR™ system also assisted in reducing the BTEX levels as well (see attached Table 2).

EARTH (Canada) Corporation's TORR™ technology offers several advantages for treating hydrocarbon-contaminated groundwater over more traditional treatment methods.

1. TORR™ separates free-floating and emulsified oils in water.
2. Recovered hydrocarbons can be reused or recycled.
3. No additional heat or chemicals are required to break the emulsions.
4. No waste is created saving additional landfill costs.
5. TORR™ has a small footprint allowing for easy transportation to remote treatment sites.
6. Treated groundwater meets and exceeds environmental regulations.
7. Costs for treatment of groundwater are lowered and can be more easily predicted for budgeting purposes.
8. Operational energy requirements and maintenance are minimal.

Bill Vriens, General Manager of Groundwater Control Systems Inc. comments, "I feel relatively confident that we were able to save a considerable amount of money with the systems we provided". The groundwater treatment project at Fort Smith was completed sooner than originally estimated.

Table 1: Process Comparison for Oil & Grease Removal

Process	Advantages	Disadvantages
Gravity Separation: API, CPI, PPI	Effective removal of free and dispersed oil; simple and economical treatment operation	Limited efficiency for removal of emulsified oil; restricted to the removal of oil droplets greater than 150 µm for API and 30 µm for CPI and PPI
Air Flotation: DAF; IAF	Effective removal of dispersed and emulsified oil in the range of 100 to 1000 ppm in the feed water with chemical addition; reliable process	Chemical sludge handling when coagulants are used
Hydrocyclones: Static and Dynamic Hydrocyclones	High separation performance is maintained with feed oil concentrations up to 2000 ppm.	Are most effective for droplets larger than 15 to 20 µm; performance declines with > 2 to 4 % oil concentrations; high g-force required (1000-3000 g)
Centrifuges	Effective removal of emulsified oil down to 3 to 7 µm.	Cannot compete with other technologies when oil droplets are above 20 to 30 µm in terms of cost effectiveness; high capital & maintenance costs.
Filtration: Sand, Anthracite, Nut Shells, multimedia	Effective removal of dispersed and emulsified oil	Requires replacement or backwashing of the medium; creates subsequent treatment and disposal problems performances vary widely
Granular Activated Carbon	Effective removal of all components including soluble oils	Poor pick-up ratio (0.1 g oil / g GAC); requires regeneration or replacements, cannot be used for oil feed concentrations higher than 100 ppm or large flows because of the high maintenance costs
Membrane Processes: Reverse Osmosis; Ultrafiltration; micro and nano-filtration	Effective removal of soluble oil	Low flux-rates; membrane fouling and limited membrane life in presence of emulsions, need extensive pretreatment
TORR™ System	Effective removal of free, dispersed and emulsified oil down to 2 µm; high performances maintained with oil feed up to 10 %; low maintenance cost, couple of cartridges must be replaced every 6 to 12 months	High levels of suspended solids will induce fouling of the first cartridge and thus need replacement; high capital cost

Figure 1 - TORR System Performance vs. Quanitity of Oil Absorbed

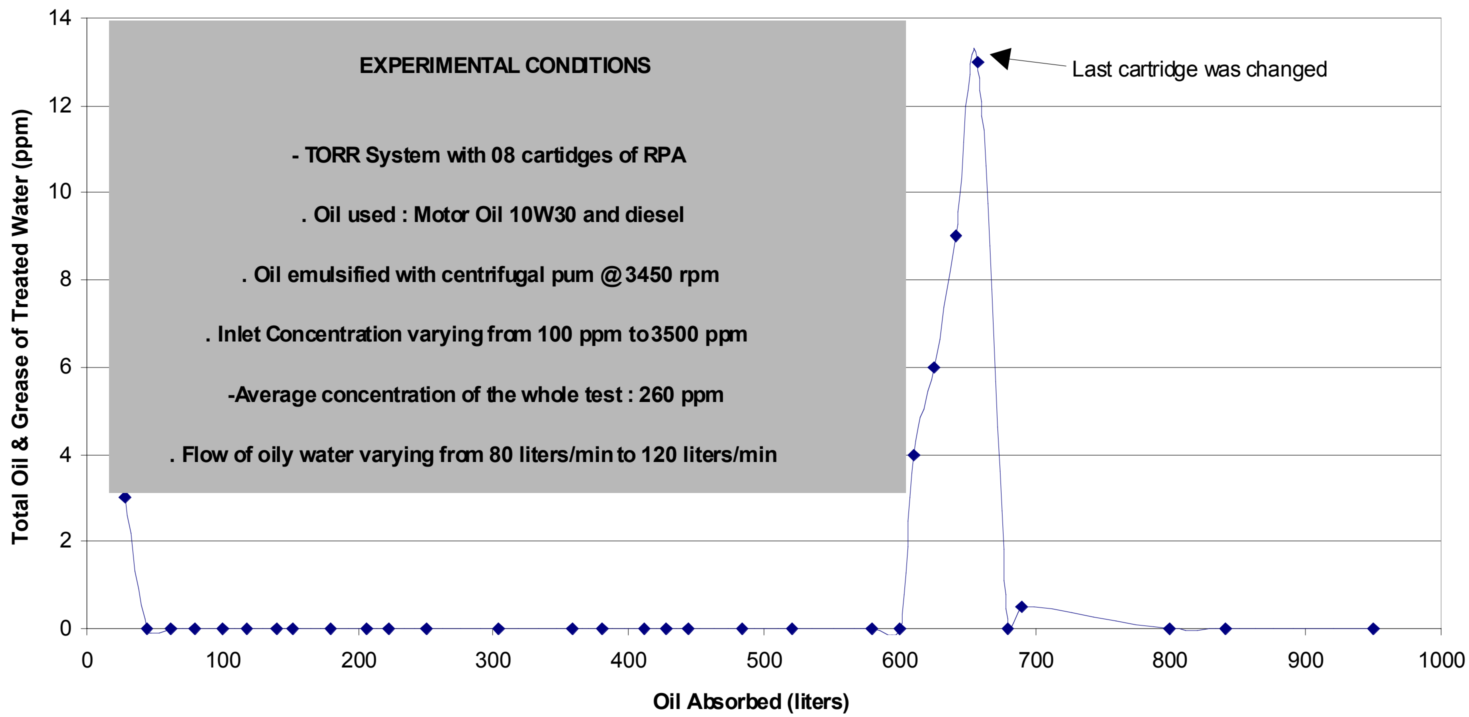

Table 2:Fort Smith (NWT) Aurora College Remediation Project On-site Testing Results

Date (mm-dd)	Time (hh:mm)	Sample (H#, ST, PT Dat, DDS)	Totalized Discharge (m^3)	On-Site Results BTEX (ppm)	On-Site Results TPH (ppm)	ETL Results BTEX (ppm)	ETL Results TPH (ppm)
26-Jul	8:47	ST	O	3.55	0.00	0.00	0.00
26-Jul	13:00	DAT	5.28	0.12	0.00	0.00	0.00
26-Jul	17:07	DAT	14.92	0.13	0.00	0.00	0.15
27-Jul	8:49	DAT	250.09	0.12	0.31	0.00	0.15
27-Jul	11:10	DAT	282.24	0.37	0.00	0.00	0.15
27-Jul	17:48	DAT	350.77	0.16	0.09	0.00	0.15
28-Jul	8:36	DAT	602.28	0.02	0.26	0.00	0.15
28-Jul	10:04	PT	-	3.90	0.59	0.00	0.15
28-Jul	12:46	DAT	652.62	0.52	5.66	0.00	0.15
28-Jul	17:05	DAT	725.56	0.66	0.23	0.00	0.15
29-Jul	8:32	DAT	993.68	0.05	0.49	0.00	0.32
29-Jul	14:00	DAT	1092.28	0.02	0.47	0.00	0.00
29-Jul	17:00	DAT	1151.16	0.02	0.47	0.00	0.00
29-Jul	20:46	DAT	1226.45	0.02	0.50	0.00	0.00
30-Jul	8:34	DAT	1454.78	0.12	0.12	0.00	0.00
30-Jul	17:00	DAT	1510.97	0.28	0.10	0.00	0.26
30-Jul	20:57	DAT	1590.53	0.25	0.06	0.00	0.19
31-Jul	8:57	DAT	1801.51	0.06	0.07	0.00	0.26
31-Jul	9:58	H5	-	0.12	5.13	0.00	0.36
31-Jul	13:34	DAT	1929.06	0.05	0.02	0.00	0.15
31-Jul	17:03	DAT	1998.88	0.19	0.01	0.00	0.15
31-Jul	17:15	H5	-	0.44	1.65	0.00	0.15
31-Jul	21:00	DAT	2102.91	0.06	2.91	0.00	0.17
1-Aug	8:23	DAT	2612.65	0.38	0.32	0.00	0.45
1-Aug	8:29	H5	-	6.55	0.43	0.01	0.15
1-Aug	12:18	DAT	2796.76	0.06	0.16	0.00	0.15
1-Aug	17:03	DAT	3012.95	0.42	0.20	0.01	0.15
1-Aug	21:03	DAT	3195.60	0.47	0.32	0.01	0.43
2-Aug	8:16	DAT	3712.95	0.49	0.76	0.01	0.19
2-Aug	8:25	H5	-	2.33	1.44	0.01	0.15
2-Aug	12:17	DAT	3802.50	0.55	0.47	0.00	0.76
2-Aug	17:34	DAT	3995.01	0.29	0.21	0.00	0.31
2-Aug	17:34	H5	-	1.07	0.71	0.00	0.15
2-Aug	21:03	DAT	4078.30	0.29	0.13	0.00	0.29
3-Aug	8:11	DAT	4386.17	0.12	0.09	0.00	0.26
3-Aug	8:08	H5	-	0.05	0.05	0.00	0.15
3-Aug	12:27	H4	-	1.47	1.22	0.00	0.00
3-Aug	12:30	DAT	4568.04	0.36	0.46	0.01	0.20
3-Aug	17:25	H5	-	0.84	0.52	0.02	0.15

3-Aug	17:31	DAT	4790.51	0.26	0.34	0.01	1.70
3-Aug	21:12	DAT	4938.27	0.34	0.38	0.01	0.27
4-Aug	12:31	DAT	5460.51	0.43	0.05	0.01	0.76
4-Aug	12:04	H4	-	4.14	0.23	0.04	0.25
4-Aug	17:20	DAT	5636.01	0.43	0.42	0.02	0.91
4-Aug	17:25	H3	-	19.31	0.84	0.02	0.53
4-Aug	21:05	DAT	5835.84	0.13	0.04	0.00	0.00
5-Aug	9:08	DAT	6499.50	0.47	0.51	0.00	0.00
5-Aug	9:11	H4	-	2.12	0.86	0.00	0.00
5-Aug	11:00	H2	-	3.63	2.13	0.00	0.00
5-Aug	12:00	DAT	6637.51	0.40	0.44	0.00	0.00
5-Aug	17:00	DAT	6909.20	0.21	0.17	0.00	0.00
5-Aug	17:05	H5	-	0.25	0.23	0.00	0.00
5-Aug	20:57	DAT	7077.20	0.44	0.49	0.00	0.00
6-Aug	9:00	DAT	7730.15	0.45	0.71	0.00	0.00
6-Aug	11:45	DAT	7884.75	0.39	0.43	0.00	0.00
6-Aug	17:48	DAT	8164.81	0.30	0.51	0.00	0.00
6-Aug	17:55	H5	-	0.62	0.68	0.00	0.00
6-Aug	8:06	DAT	8914.81	0.03	0.82	0.00	0.00
7-Aug	n/a		n/a	0.46	0.40	0.00	0.00
7-Aug	11:55	DAT	9083.25	0.33	0.28	0.00	0.00
7-Aug	17:30	H6	-	0.02	0.02	0.00	0.00
7-Aug	18:05	DAT	9370.76	0.22	0.36	0.00	0.00
7-Aug	21:40	DAT	9512.11	0.50	0.95	0.00	0.00
8-Aug	8:00	DAT	9941.16	0.18	0.10	0.00	0.00
8-Aug	7:55	H6	-	0.02	0.03	0.00	0.00
8-Aug	9:50	H3	-	1.80	1.98	0.00	0.00
8-Aug	9:05	H4	-	0.49	0.74	0.00	0.00
8-Aug	9:05	H5	-	0.32	0.66	0.00	0.00
8-Aug	12:00	DAT	10091.02	0.14	0.10	0.00	0.00
8-Aug	14:03	H1	-	0.57	0.70	0.00	0.00
8-Aug	14:35	H2	-	0.76	1.21	0.00	0.00
8-Aug	18:05	DAT	10344.56	0.30	0.23	0.00	0.00
8-Aug	21:03	DAT	10507.60	0.21	0.11	0.00	0.00
9-Aug	8:06	DAT	10954.15	0.13	0.12	0.00	0.00
9-Aug	9:30	H1	-	0.88	0.81	0.00	0.00
9-Aug	9:30	H2	-	9.47	2.69	0.00	0.00
9-Aug	9:30	H4	-	0.28	0.24	0.00	0.00
9-Aug	9:30	H5	-	0.34	0.27	0.00	0.00
9-Aug	9:30	H6	-	0.02	0.02	0.00	0.00
9-Aug	12:00	DAT	11123.50	0.12	0.09	0.00	0.00
9-Aug	17:30	DAT	11398.31	0.08	0.08	0.00	0.00
9-Aug	22:00	DAT	11589.34	0.17	0.12	0.00	0.00
10-Aug	8:05	DAT	12065.21	0.26	0.28	0.00	0.00
10-Aug	12:00	DAT	12253.22	1.54	1.16	0.00	0.00
10-Aug	13:30	H1	-	0.87	0.61	0.00	0.00
10-Aug	13:30	H2	-	6.66	4.74	0.00	0.00
10-Aug	13:30	H4	-	0.49	0.45	0.00	0.00

Back
to previous page

10-Aug	13:30	H5	-	0.72	0.69	0.00	0.00
10-Aug	13:30	H6	-	0.03	0.03	0.00	0.00
10-Aug	13:30	DAT	12296.55	0.81	0.87	0.00	0.00
10-Aug	18:05	DAT	12530.80	0.46	0.45	0.00	0.00
10-Aug	21:17	DAT	12684.40	0.38	0.57	0.00	0.00
11-Aug	8:45	DAT	13256.74	0.10	1.62	0.00	0.00
11-Aug	10:03	DAT	-	0.56	0.44	0.00	0.00
11-Aug	13:15	DAT	13396.71	0.15	0.06	0.00	0.00
11-Aug	18:11	DAT	13624.75	0.52	0.88	0.00	0.00
11-Aug	21:35	DAT	13784.60	0.47	0.88	0.00	0.00
12-Aug	8:49	DAT	14293.82	0.20	0.59	0.00	0.00
12-Aug	12:03	DAT	14431.83	0.14	0.30	0.00	0.00
12-Aug	17:34	DAT	146800.71	0.10	0.35	0.00	0.00
12-Aug	21:06	DAT	148410.70	0.16	0.63	0.00	0.00