Subject: Voluntary Safety Guidelines for Organic Rankine Cycle Systems (for consultation)

The purpose of this OE Safety Bulletin is to outline TSSA’s voluntary safety guidelines for Organic Rankine Cycle (ORC) Systems in Ontario.

Pressure boundary systems in Ontario are currently regulated by TSSA under the Boilers and Pressure Vessels (BPV) Regulation and the Operating Engineers (OE) Regulation. The BPV Regulation regulates the design, construction and installation of boilers and pressure piping, as well as the periodic inspection of boilers and pressure vessels. The OE Regulation regulates the operation of steam plants, including attendance requirements, as well as the periodic inspection of steam plants.

Steam power plants are Rankine Cycle systems that boil water to convert high-temperature energy sources into mechanical energy and/or electrical energy. Recovering thermal energy from low-grade heat sources and converting it to electrical power is not practical with ordinary Steam Rankine Cycle systems. In order to recover energy from low-grade heat sources, traditional Rankine Cycles can be modified to become ORC systems by using organic working fluids with lower boiling points. ORCs allow for energy extraction and conversion of industrial waste heat, biomass energy, solar energy, and turbine waste heat, effectively converting low-grade heat sources into electrical power.

ORC systems are not specifically defined in the BPV or OE regulation, nor in any other Canadian related regulation. However, ORC systems do fall within the scope of the BPV regulation because the definition of a BPV “boiler” uses generic working fluids: “gas, vapour or liquid”. The OE regulation, on the other hand, uses “water/steam” as the working fluid for its legal definition of a “boiler”, which does not include ORCs. This means that while the boiler and pressure vessel ORC devices are covered by the current BPV regulation (and thus require registration, CRNs, P-numbers, BPV periodic inspections), there is currently no jurisdictional authority to enforce operational and safety requirements for ORC systems (i.e. registration and attendance) under the current OE regulation.

Earlier dialogue between TSSA and ORC proponents created the misimpression that ORC systems are subject to similar regulatory requirements as current steam rankine cycles under the OE regulation, but with reduced attendance requirements. To address this misimpression, TSSA recently conducted a more detailed analysis of the applicability of the OE regulation to ORC systems and confirmed that most ORC systems are outside the scope of the current OE regulation for the reasons noted above. However, it should be noted that ORC systems attached to an existing Steam Power Plant would be considered part of the steam plant and therefore subject to regulation by TSSA under the current OE Regulation.

Given the similarities of ORC to steam rankine cycle systems, TSSA has undertaken a safety analysis and has developed voluntary guidelines for the safe operation of ORC systems consistent with similar approaches taken by other Canadian jurisdictions where they are in operation.

Like Ontario, Saskatchewan only regulates steam/water boilers. As such, Saskatchewan does not regulate ORC systems. The provincial regulators consult with ORC plant owners and recommend best practices.
Alberta has the most prescribed recognition of ORC systems. ORC systems are regulated as boilers under the Power Engineers Regulation and the Pressure Equipment Safety Regulation. The Power Engineers Regulation explicitly recognizes “organic fluids” and “waste heat recovery plants”. The default requirement for operation is 24/7 power engineer supervision. “Owner-users” have the option of suspending supervision by power engineers if they meet the requirements for reduced supervision operation. An Alberta “owner-user” is an operating company that has been issued a quality management system certificate of authorization permit for its “Pressure Equipment Integrity Management System” (PEIMS). This is a quality system that covers the full life cycle of pressure equipment and is formally audited periodically by ABSA. In the case of remote supervision, the PEIMS has to address the operation and maintenance of the ORC with respect to qualifications and training of operators and maintenance personnel, inspection and maintenance of the pressure equipment and its safety controls and devices, operating procedures, risk assessment results, etc.

British Columbia currently regulates ORC systems as both an unfired power plant and a low pressure thermal fluid plant, with the former usually driving attendance requirements. ORC systems can also be assessed on a case-by-case basis under the Alternative Safety Approach (ASA) to consider using reduced attendance requirements.

One common trait of all Rankine Cycle systems is that they must pressurize and superheat the working fluid. This is the main risk factor of Rankine Cycle systems: if the boiler/evaporator ruptures during operation, the superheated working fluid would instantaneously convert from liquid to vapor creating a catastrophic explosion. This is the main contributor to the BLEVE explosiveness from a ruptured boiler/evaporator. This explosion can be significantly exacerbated if the working fluid is flammable, which could also create a Chemical explosion in addition to the BLEVE.

Thus, the severity of the potential explosion is dependent upon several variables:

1. The amount of internal energy in the vessel (pressure, temperature, thermal input)
2. The amount of superheated fluid in the vessel
3. The expansion ratio\(^2\) of the fluid
4. The flammability of the fluid

The current OE regulation assesses attendance requirements such that systems with the highest internal energy and highest fluid content (High Pressure Steam plant) are ranked as 1\(^{st}\) Class 24/7 attended plants. As the energy content and working fluid content reduces, the attendance requirements are reduced to 2\(^{nd}\) to 3\(^{rd}\) to 4\(^{th}\) class attended requirements (24/7 or 8hr/day) to unattended to exempt. The expansion ratio and flammability are not factors in current attendance requirements since the expansion ratio is the same for all current systems, and water is not flammable.

In the case of ORCs, however, the expansion ratio and flammability of the organic working fluids are contributing risk factors, in addition to internal energy and fluid volume that apply to both steam and ORC systems, in considering attendance requirements:

a. The expansion ratio of water is 1,603 (i.e. 1 litre of water would expand into 1,603 litres of steam at 100°C), and is common for all current Rankine Cycle systems. The expansion ratio for typical organic working fluids\(^3\) is much less than water, with cyclopentane at 259, R245FA (Pentafluoro propane) at 240, pentane at 210, MM (Hexamethyldisiloxane) at 116 and MDM (Octamethyltrisiloxane) at 84. This greatly reduces the explosive effect of a sudden rupture of an ORC evaporator.

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1 Boiling Liquid Expanding Vapour Explosion is an explosion that occurs when superheated liquid at high pressure instantaneously converts to its vapour form if the pressure containment fails.
2 Expansion Ratio of a fluid is defined as the ratio of the specific volume of a vapour over the specific volume of its liquid state. This should not be confused with Coefficient of Thermal Expansion, which does not involve a phase change of the fluid.
3 Typical working fluids are defined as those currently being utilized or proposed by ORC proponents.
b. Water is not flammable and thus the flammability hazard does not apply. For typical organic working fluids, there is a wide range of flammability, with cyclopentane at highly-flammable, R245FA at non-flammable, pentane at extremely-flammable, MM at highly-flammable and MDM at flammable.

By virtue of the much lower expansion ratios of ORC working fluids, TSSA recognizes that ORC systems do warrant reduced attendance requirements based on the reduced BLEVE hazard, but still require voluntary safety oversight due to energy content and explosion risk. The flammability aspect of the working fluid is recognized below by virtue of different attendance thresholds and requirements.

TSSA recognizes that it does not have jurisdiction to enforce operational requirements for ORC plants under the current OE regulation. However, given the identified hazards associated with ORC systems and the similarity in operating requirements to steam Rankine Cycle systems, TSSA has identified a potential public safety risk to Ontarians.

Going forward, TSSA is outlining the following voluntary safety guidelines for the operation of ORC systems using the current OE regulation classification system as a guide:

- ORC plants with an energy content hazard above 736 kWth are recommended to submit a Record of Plant Location with TSSA as a unique ORC plant with guarded controls. As will be described further below, it is recommended that ORC plants would be a unique plant type with reduced attendance requirements from steam plants.
- B44 - part-time attendance (8hr/day) as a 3rd Class Plant is recommended for plants with an energy input threshold greater than 14,715 kWth, utilizing flammable working fluids
- B45 - part-time attendance (8hr/day) as a 4th Class Plant is recommended for plants with an energy input threshold greater than 24,524 kWth, utilizing non-flammable working fluids.
- B43 – all other ORC plants > 736 kWth but less than the above thresholds are recommended to submit a Record of Plant Location with TSSA and be periodically inspected as per all other regulated unattended Rankine Cycle plants, but operate unattended.
- Note: ORC systems typically are rated by their output power (kWth). When input energy is not stipulated, it can be estimated by dividing kWth by 0.18 (representing a typical system efficiency of 18%).

Unattended plants are recommended to be protected with guarded controls and have a maintenance plan in place. If the ORC operator opts to participate in the voluntary submission of the Record of Plant Location and subsequent periodic inspections of the plant, the TSSA OE inspector would ensure that the maintenance plan was properly implemented, all guarded controls are working correctly, the evaporator has a current Certificate of Inspection, and the plant is in safe operating condition. TSSA would provide safety recommendations for operators' consideration to address unsafe conditions identified during an inspection.

The above voluntary guidelines apply only for the OE regulatory requirements. ORC systems that do fall within the BPV regulation shall require CRNs for pressure vessels and P-numbers for piping, first inspections from TSSA and will require periodic inspections of the pressure vessels by TSSA or an insurer.

Participation in the voluntary ORC system safety guidelines would not incur any charges from TSSA for the submission of the Record of Plant Location or inspections.

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4 Flammability as designated in related Material Safety Data Sheet (MSDS)
5 The voluntary Record of Plant Location submission process will be the same as the current OE Plant registration process.
TSSA welcomes feedback on the details of the voluntary safety guidelines from the broader industry sector, in particular ORC manufacturers, operators and consulting engineers working with or knowledgeable about ORC systems. The consultation period will be open until July 15, 2016. Comments can be provided via TSSA’s website: www.tssa.org.

Additionally, TSSA intends to engage with the broader sector to assess compliance with this voluntary safety guideline and to assess safety outcomes in order to consider any additional steps required to ensure public safety.

Any questions or comments regarding this advisory can be directed to TSSA’s BPV/OE Safety Program Director Mike Adams at madams@tssa.org.

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