

GASKET FAILURE ON A CLEAR JUICE PLATE HEAT EXCHANGER AT TSB, MALELANE

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Abstract

The TSB Malelane factory uses a 5 mm gap plate heat exchanger (PHE) on clear juice duty. Repeated failure of the original equipment manufacturer's (OEM) gaskets resulted in substantial unit downtime and considerable cost. Causes of the gasket failures were investigated and several process control solutions were implemented with limited success. Investigations were then targeted at the gasket material specification. This paper examines the use of a locally manufactured gasket and the factors that were considered in determining a suitable alternative gasket material specification.

Keywords: plate heat exchanger, gasket failure, Malelane

Introduction

The Malelane mill clear juice heating station comprises two PHE units in parallel, designed to handle a factory juice flow of 450 m³/h. The design working data for the PHE units are as follows:

- Juice feed temperature : 98°C
- Juice final temperature : 114°C
- Exhaust steam temperature : 127°C
- Pressure drop : 62 kPa
- Juice side gap : 5 mm
- Steam side gap : 5 mm
- No. of plates per heater : 180
- Heating surface per heater : 148 m².

Since their installation in 1990 the units have not functioned satisfactorily, the main problems being:

- fouling of the juice channels with bagacillo/caramel deposits
- juice side leaks
- gasket failures.

TSB staff have acknowledged that the gap size on the plate heat exchangers was incorrectly specified for Malelane type clear juice. However, it was decided to persevere with attempts to improve the operation of the units because of their high capital investment.

Process control steps taken to reduce/eliminate gasket failure

Elimination of dismantling for cleaning

From inception it was realised that dismantling of the PHE resulted in a high incidence of gasket failure (Coetzee, 1994). To eliminate the need for opening the units, cleaning has been addressed by implementing cleaning in process (CIP) with a 5% caustic soda solution at two week intervals. More frequent cleaning would be preferable but, due to lack of standby capacity, this operation was deferred to shutdown days. In addition, Distributed Control System (DCS) automatic controlled reverse flow every 120 minutes was introduced to eliminate the accumulation of juice side suspended solids between plates. Inspection of the plates at the end of the season revealed fouled areas that had resulted from poor juice flow over some of the juice channels. This manifested itself as a carbonaceous scale-like deposit that was not affected by CIP but was easily removed by immersing the dismantled plates in a boiling caustic bath. The loss in heating surface resulting from this fouling was not considered a severe handicap, since the clear juice temperature did not drop below 112°C when the steam control valve was fully open. This cleaning was therefore deferred to the end of the season.

Causes of juice and steam leaks

When each unit was opened, the entire set of PHE seals had to be replaced as they had become brittle and were easily damaged when handled. Of greater concern, from both safety and loss of product aspects, were the persistent leaks from the PHE when put back into service.

The source of the problems was traced to:

- pulsating flow when the reverse juice flow automatic valves changed over
- liquid hammer when the clear juice pump tripped
- high clear juice line pressures (intermittent) due to juice flow changes
- rubber seals being extruded from between plates.

The problem was exacerbated by the fact that, when the PHE was opened to replace leaking gaskets, other gaskets would fail as a result of handling. The heaters were eventually shut down and clear juice was fed directly to the evaporator first effect vessels without any adverse effects. This was possible due to

lower throughputs (resulting from the reduced cane crop) for the past two seasons. The exercise refocused attention on determining the optimum temperature for clarified juice prior to its being fed into the evaporator first effect. Mill staff will experiment with lower juice temperatures when higher throughputs can again be attained. In anticipation of normal cane supply in the 1997-98 season, the PHE problems were revisited to ensure that these units would be available for service at higher crush rates without the handicaps identified above.

Elimination of liquid hammer

The liquid hammer problem associated with reverse flow has been addressed by slow valve change-over achieved by slow ramp action from the DCS. In addition, automatic block valves

have been installed on the clarified juice pumps and these have been configured to shut automatically in the event of a pump trip and so prevent hammer when the pump is restarted.

Elimination of high line pressure

High clear juice line pressure due to variation in juice flow into the evaporator has been addressed by:

- implementation of an automatic cascade clear juice tank level/ clear juice flow control loop
- installation of an automatic pressure control metal-seated relief valve in the clear juice line to prevent line over pressure. The maximum pressure has been set at 400 kPa and the return from the relief valve discharges into the clear juice tank.

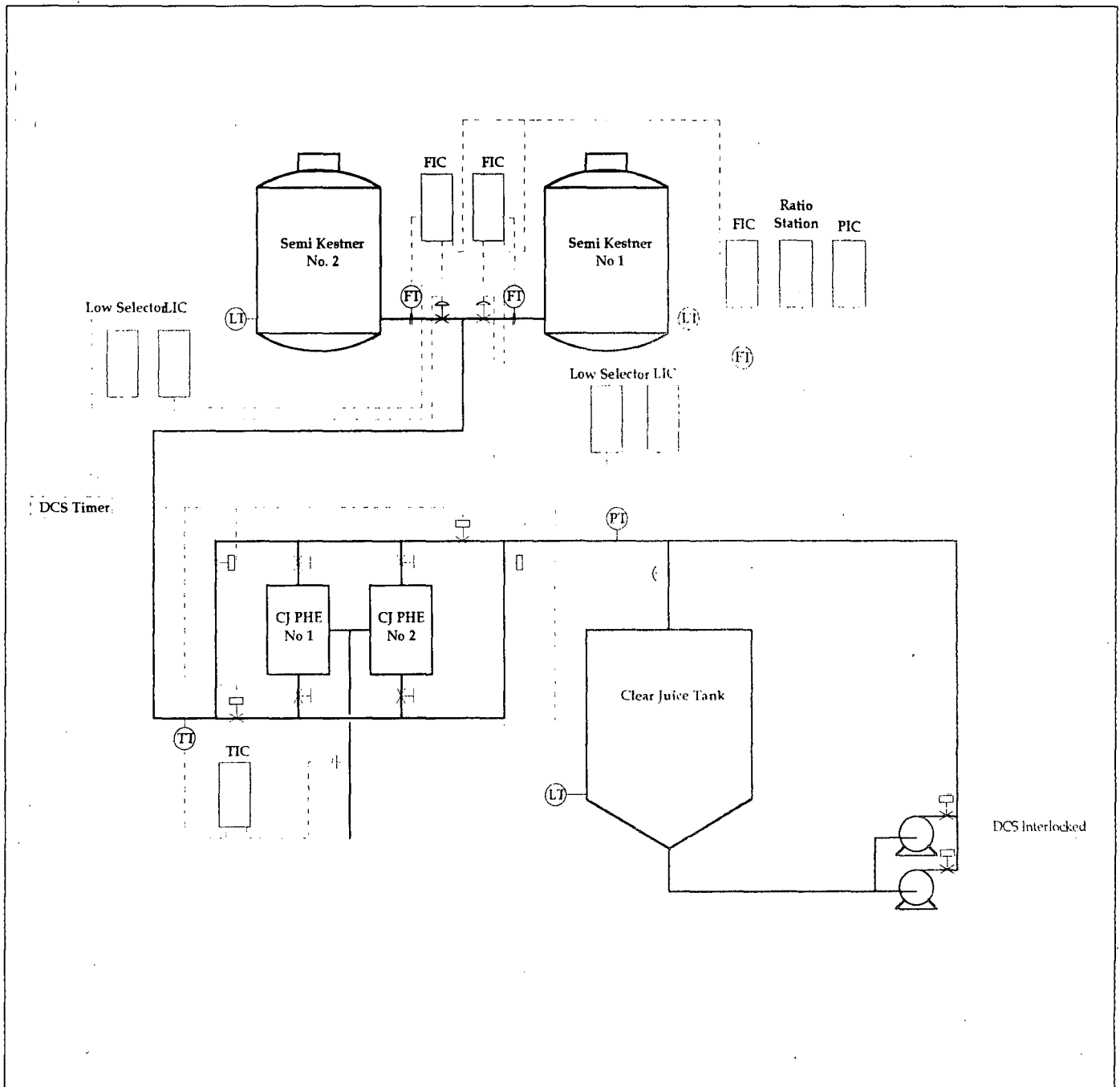


Figure 1. P&ID: Malelane clear juice station, 1996.

The piping and instrumentation diagram (Figure 1) depicts the instrumentation installed around the clarified juice station to even out juice flow and to prevent line over pressure. These steps achieved the desired process control objectives, but gasket leaks persisted.

Rubber specification changes to reduce/eliminate gasket failure

At the same time as the last of the process control modifications were being implemented, the rubber specification of the PHE gaskets was re-examined with a view to improving shelf and service life. The OEM gaskets in use had a limited shelf life, and after approximately six months in storage new gaskets displayed cracks which developed into full fractures during installation.

Given the high replacement costs of these gaskets (R182 000 per annum) it was decided to examine more cost effective alternatives. TSB considered rehabilitating a set of redundant shell and tube heaters for this duty, but before this step was taken it was decided to investigate alternative rubber specifications for the PHE gaskets. A local manufacturer of rubber gaskets was approached to supply a seal to meet the following specifications:

- continuous exposure to high temperature (130°C)
- high pressure rating (400 kPa)
- long storage life
- re-use after the PHE was opened for inspection/cleaning
- compressibility without deformation to prevent leaks.

The factors considered in the selection of a better rubber formulation to meet these specification are discussed below.

Specification to meet continuous high temperature duty

With an exhaust steam operating temperature of 125 to 130°C and potentially peaking at 150°C, it was necessary to employ a rubber compound which would perform adequately in this range. While the temperature resistant properties of the rubber were stressed as paramount, the following additional considerations had to be met:

- non-toxicity in a food application
- mechanical integrity in terms of longevity as a fluid seal
- sound storage and handling characteristics when exposed to environmental conditions.

A potential candidate material which satisfied the temperature conditions and the non-toxicity parameter was acrylonitrile-butadiene rubber (Nitrile or Buna N). This material can be stabilised to operate up to 120°C in closed environments, and is non-toxic to Food and Drug Administration (FDA) regulations for use in food applications. The major problem, however, is the relatively poor ability of the material to withstand contact with air over long periods in storage, or shorter periods at ele-

vated temperatures. This problem accounted for the commonly noticed cracks on the OEM gasket when taken from storage, and the inability of the gasket to be re-used on re-assembling the heat exchanger unit.

As Nitrile did not fulfil all the above criteria, it was discarded and silicone was examined as an alternative. Silicone rubber is extensively used in sealing applications, including use as heat exchanger gaskets. It is non-toxic in contact with food, has excellent longevity in sealing applications, and is extremely resistant to thermal and oxidative degradation up to 200°C. However, resistance to hydrolysis at 130°C in direct contact with steam of presently available silicone formulations is still a problem area. This prompted investigation into alternatives with properties better suited to heating clarified juice with high temperature steam.

The most readily available rubber to keep costs down was the range of materials based on ethylene and propylene. These materials have found extensive use in sealing applications as they are resistant to a wide range of industrial chemicals and to oxidative degradation in storage, and have good retention properties at high temperatures. Ethylene-propylene terpolymer (EPDM) performs well at 60 to 160°C, and in addition has the required characteristics to meet the demands of this application. The non-toxic criteria can be achieved by removing from the finished gasket material any volatile products of the vulcanisation, and careful selection of the compounding ingredients to meet FDA standards.

Specification to meet high pressure (400 kPa) duty

The design of the PHE stainless steel plate and the rubber seal profiles are such as to ensure containment of the operating pressures. The pressure rating is a direct function of the hardness of the rubber compound. Should the rubber compound be too soft, the gasket would tend to extrude from between the plates and allow the pressure to escape. Conversely, if the rubber is too hard, this would result in lack of compressibility, inability of the rubber seal to mould into the plate profile and a consequent loss of pressure. The OEM gaskets had a hardness of 75° ±5° Shore A and this value served as the starting point in the degree of hardness selection. All the test seals manufactured had a hardness within this range and proved adequate for the pressure duty.

Specification to meet shelf-life

To ensure that the seals met the requirement for storage, viz. no cracking, EPDM was chosen because of its excellent shelf life, supported by its temperature and pressure rating properties. Attention was also paid to the manner of storage. In the event of the gaskets being hung from a peg, the rubber would suffer flex fatigue, i.e. fatigue resulting from repeated distortion by bending, extension or compression. The failure originating from this source is referred to as 'flex cracking' and manifests itself as surface cracks around the point of suspension. The gasket would tend to fail around this point. It could not be confirmed

whether this had been occurring with the Malelane gaskets, and to eliminate the likelihood of this type of failure the gaskets will be laid flat in a cool place.

Specification to allow re-use of gaskets

When, after assembly, the lateral studs of the PHE are tightened to compress the rubber gaskets between the stainless steel plates, the rubber becomes distorted under the tightening load. When rubber is held in this manner over a period, it will suffer compression set (CS), which is the difference between the original thickness and the thickness after compression has been relaxed. This state is aggravated under high temperature conditions. The ability of a rubber compound to resist permanent deformation from compressive forces depends on the state of cure of that rubber, and the type of cross-links introduced to the elastomeric network. The sealing material required for a PHE needs to be:

- flexible, in order to cope with the irregularities in and between plates
- compression resistant, to contain the pressure.

The problem encountered in compounding an elastomeric material to optimise these properties is that they are antagonistic. Ultimate compression resistance can be achieved but at the expense of flexibility, and *vice versa*. Further complexity is introduced due to the temperature sensitivity between the compression set and the state of cure. This is shown in Figure 2.

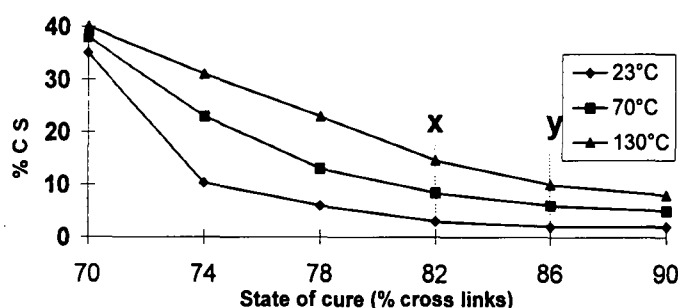


Figure 2. State of cure versus compression set.

These data were obtained from historical records (EE du Pont de Nemours, 1963), and are representative of CS and state of cure values for the rubber formulation under consideration. The temperature conditions are typical of the conditions to which the PHE seals would be exposed at normal state of cure and subsequently during operation. It is evident that at each progression the elasticity of the rubber decreases. Bearing this in mind and the fact that there was no specification from which to work, the selection of the trade-off point between flexibility and compressibility had to be determined by trial and error. The starting point for the initial trial set of gaskets was selected with a typical property range shown as (x) in Figure 2. The characteristics obtained from a bench test (Appendix 1) for the seal were:

- at the normal state of cure, at 23°C, the compression set (CS) was $\pm 3\%$
- at 70°C this moved to $\pm 8\%$ and
- at 130°C the CS reached $\pm 15\%$.

Having decided on the material specification it was required to fabricate moulds matching the profiles of the steam and juice rubber gaskets. After studying the plates it was determined that one configuration of gasket would serve both steam and juice side applications, requiring the fabrication of one mould only.

The outcome of the first trial (Singh, 1996) revealed that the rubber seals were inadequate in terms of their high CS characteristic and high elasticity factor under operating conditions. This manifested itself in the rubber seal material being extruded under pressure, resulting in leaks and providing no opportunity for re-use of the gaskets. By increasing the cross-link density (state of cure) to the point shown as (y) in Figure 2, this problem was addressed and leaks were eliminated.

While the level of CS may be modified as shown above, another condition known as stress relaxation or creep develops which affects the number of times that the gasket may be re-stressed. This is due to the fact that all elastomers show gradual increase in deformation under constant load with passage of time. There is no standard method of predicting creep, and this presents uncertainty in determining how many times a gasket may be re-used. To realise the optimum resilience of the rubber compound, the gasket should not be compressed to less than 20% of its original dimension.

Given the CS selected above, this should allow for the set of gaskets to be re-used at least once. The set of gaskets in use at present have only been in service for the latter part of the past crushing season and have yet to be exposed to this test.

Cost/benefit analysis

Table 1
Cost/benefit analysis for different types of gaskets
(only relevant costs considered).

Factors	OEM gasket	New gasket
Unit price (Rand)	300	270
Replacement, start of season (Rand)	54 000	48 600
Replacement, in season (Rand)	27 000	Not required
Maintenance man-hours, in season (Rand)	10 000	Not required
Mould cost (Rand)	Nil	40 000
Five year average annual cost (Rand)	91 000	56 000
Throughput	Down time due to repairs	No down time
Other	Safety risk high Product loss risk high	Safety risk low Product loss risk low

Summary

Malelane mill started out to address leaks and gasket failure on the clarified juice PHE by implementing several process control steps. These included CIP to eliminate dismantling of the heaters for cleaning, and automation to prevent pulsating flows and liquid hammer conditions as well as control to even out flow and prevent line over pressure. These steps were successful in addressing the symptoms for which they were targeted, but leaks from the PHE gaskets persisted. Investigations were then pursued into alternative specifications for the rubber seals being used as gaskets. Several factors were considered in the selection of an ideal rubber formulation to meet the sealing duty requirements within temperature, pressure, shelf life, re-use and cost effectiveness constraints. Nitrile, silicone and EPDM type rubbers were examined. EPDM was determined as having the best temperature rating, and a hardness value corresponding to the OEM gasket was found to be adequate for the required pressure rating. The specification to meet the re-use constraint while ensuring proper sealing required a trade-off between the compressibility and elasticity properties of the rubber formulation. The ideal compression set characteristic and elasticity factor were determined by first approximating the requirements by bench testing and finally by trial and error on the PHEs. When the specification for the new seal was finalised a mould of the required profile was fabricated. During this exercise it was determined that a single seal would serve for both steam and juice applications, and thus only one mould would be required. During the test period the units were opened and closed several times and the same seals were re-used. However, due to the fact that the seals had not been in service for a long enough period, the longevity of the gasket still remains to be tested. The cost benefit analysis supports the choice of the new gaskets over the OEM gaskets on the basis of a 38% reduction in costs as well as throughput and safety benefits.

Conclusions

Attempts to resolve PHE gasket failure at Malelane indicated that locally manufactured EPDM seals can be used to replace the OEM seals at reduced cost and provide the necessary sealing at the temperature and pressure in the PHEs. The final set of seals have been in operation in one PHE for the latter part of the past season (16 weeks) without juice leaks. The benefits to Malelane mill have been reduced costs, longer life of seals, elimination of heater down time and a reduction in maintenance man-hours.

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APPENDIX 1 Test procedure

Specimens of the EPDM rubber seal at different states of cure were compressed between parallel steel plates under a stress of 28 kg/cm²:

@ 23°C for 24 h

@ 70°C for 24 h

@ 130°C for 24 h.

After each test the specimens were removed and allowed to recover for 30 minutes at room temperature. Compression set is the difference between the original thickness of the specimen and the thickness after test, expressed as a percentage of the original thickness.